Thoughts about Measuring Entrainment

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Entrainment

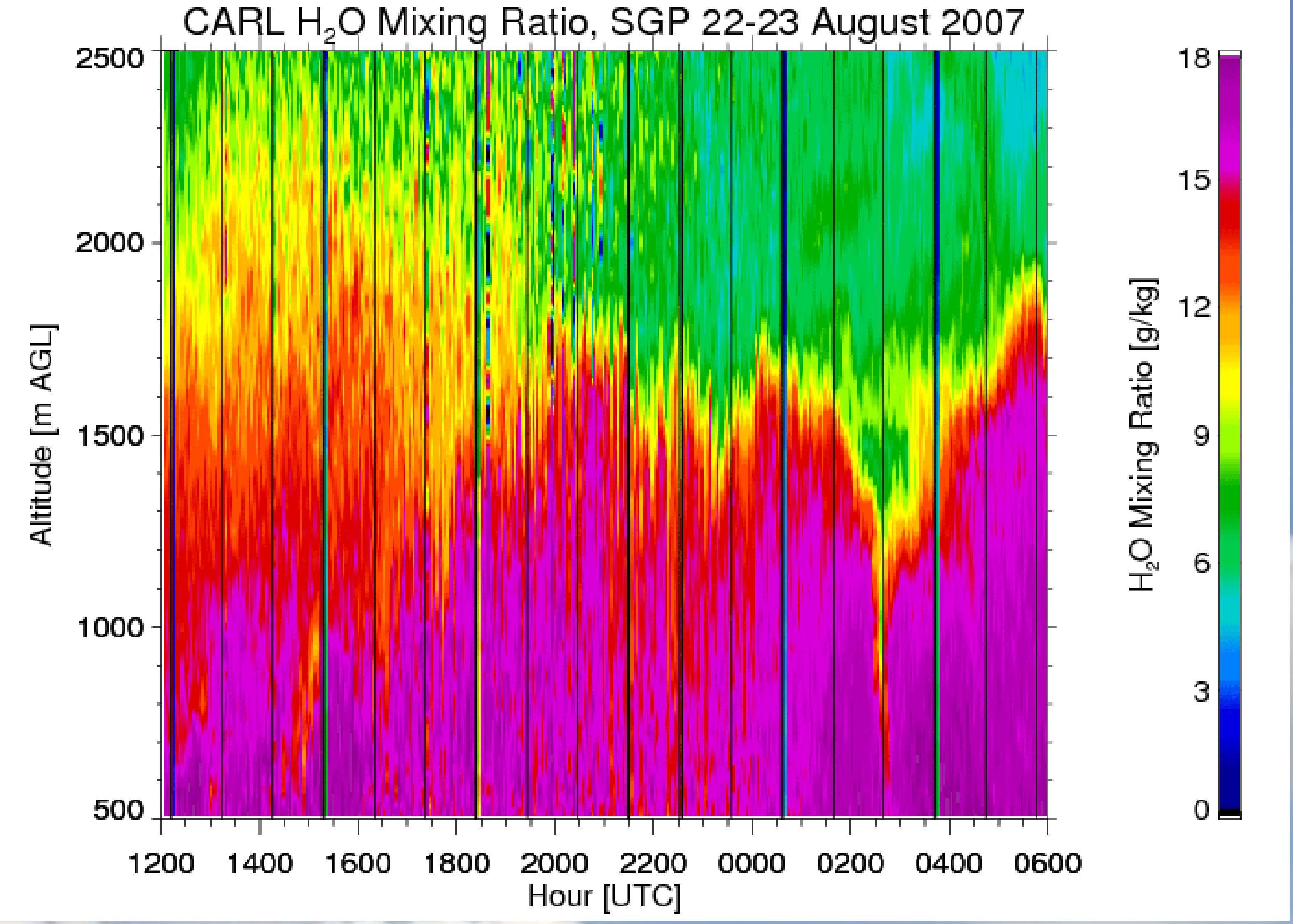
- Entrainment of dry air into the BL and moist air into the free troposphere
- Entrainment of dry air into clouds

Entraining Dry Air into BL and Moist Air into Free Troposphere

- Entrainment of moisture into middle atmosphere was highlighted as one of the two processes that exhibits the most sensitivity to GCM simulations (Sanderson et al. 2008)
- Moisture in mid-trop also hypothesized to be extremely important for development of deep convection
- Requires high vertical and temporal resolution to study this
- Raman lidar (SGP, Darwin) makes the needed observations
  - Clear skies and beneath clouds
  - Need to account for instrument noise
- Passive ground-based WV profilers (e.g., AERI, MWRP) “run out of information” at top of BL, thus vertical resolution suffers
  - Still able to get useful information out of these instruments?
  - Does combining with satellite sounders (e.g., IASI) help?

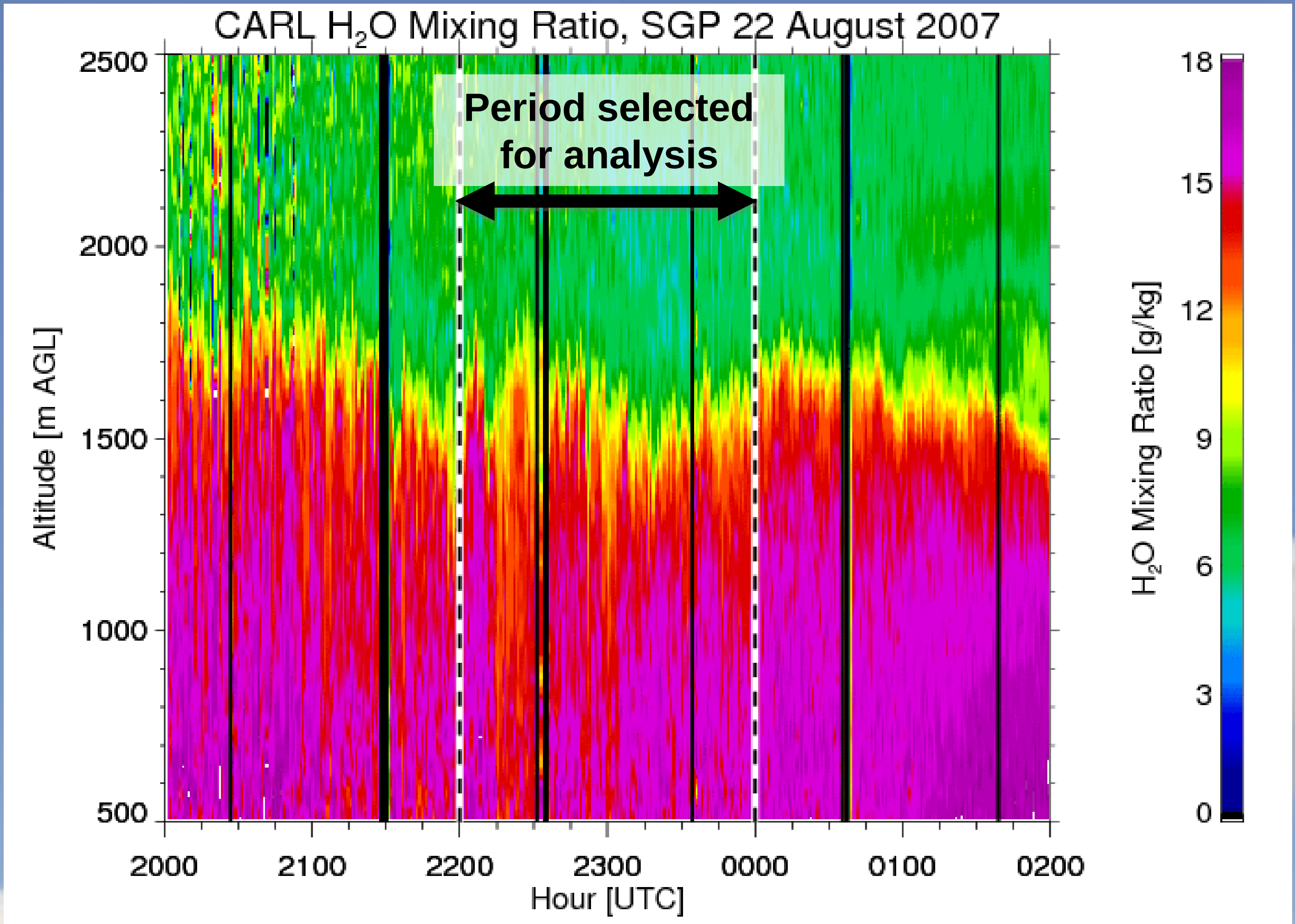
Example Time-Height Cross-Section

10-s, 75-m resolution



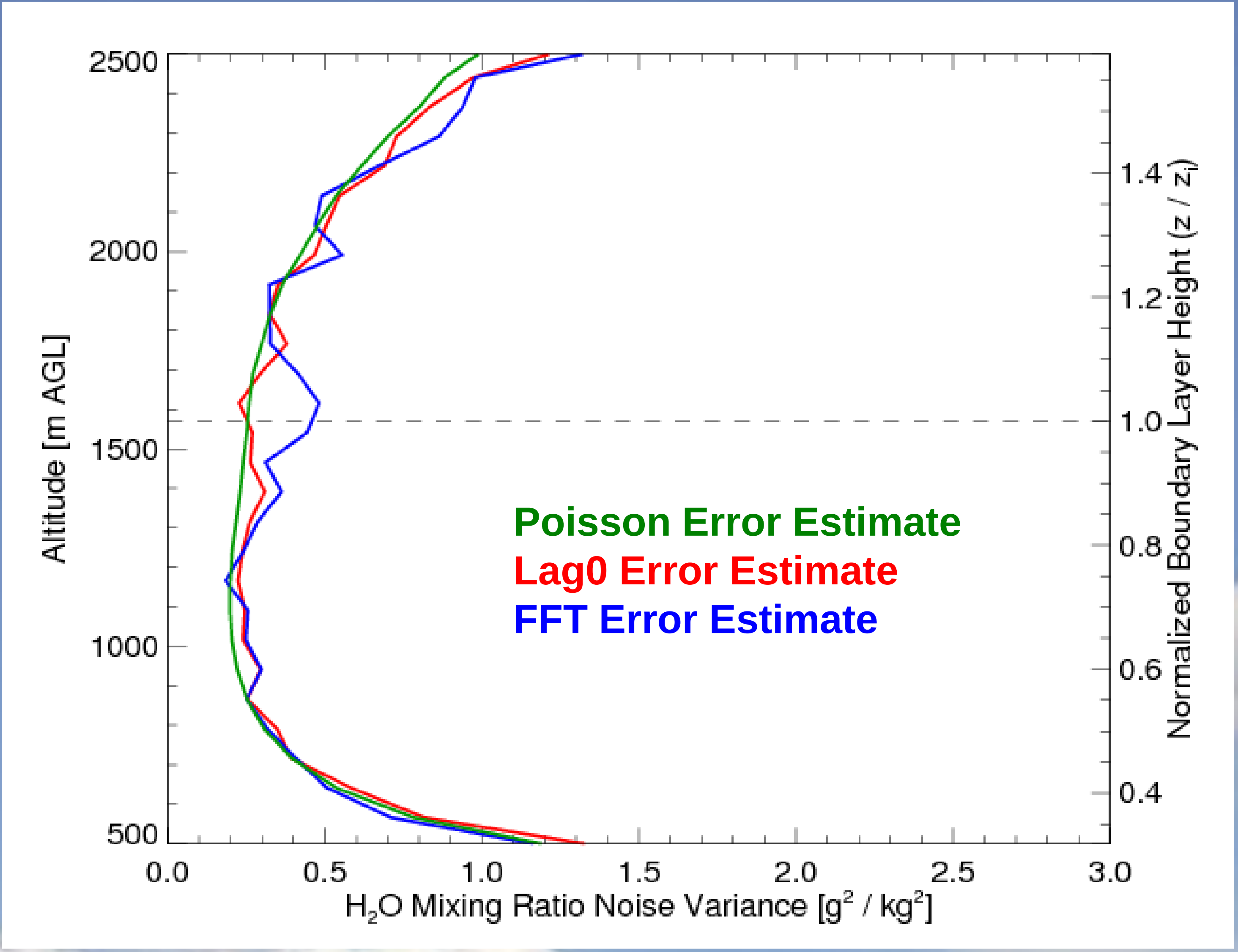
Example Time-Height Cross-Section

10-s, 75-m resolution (zoomed view)



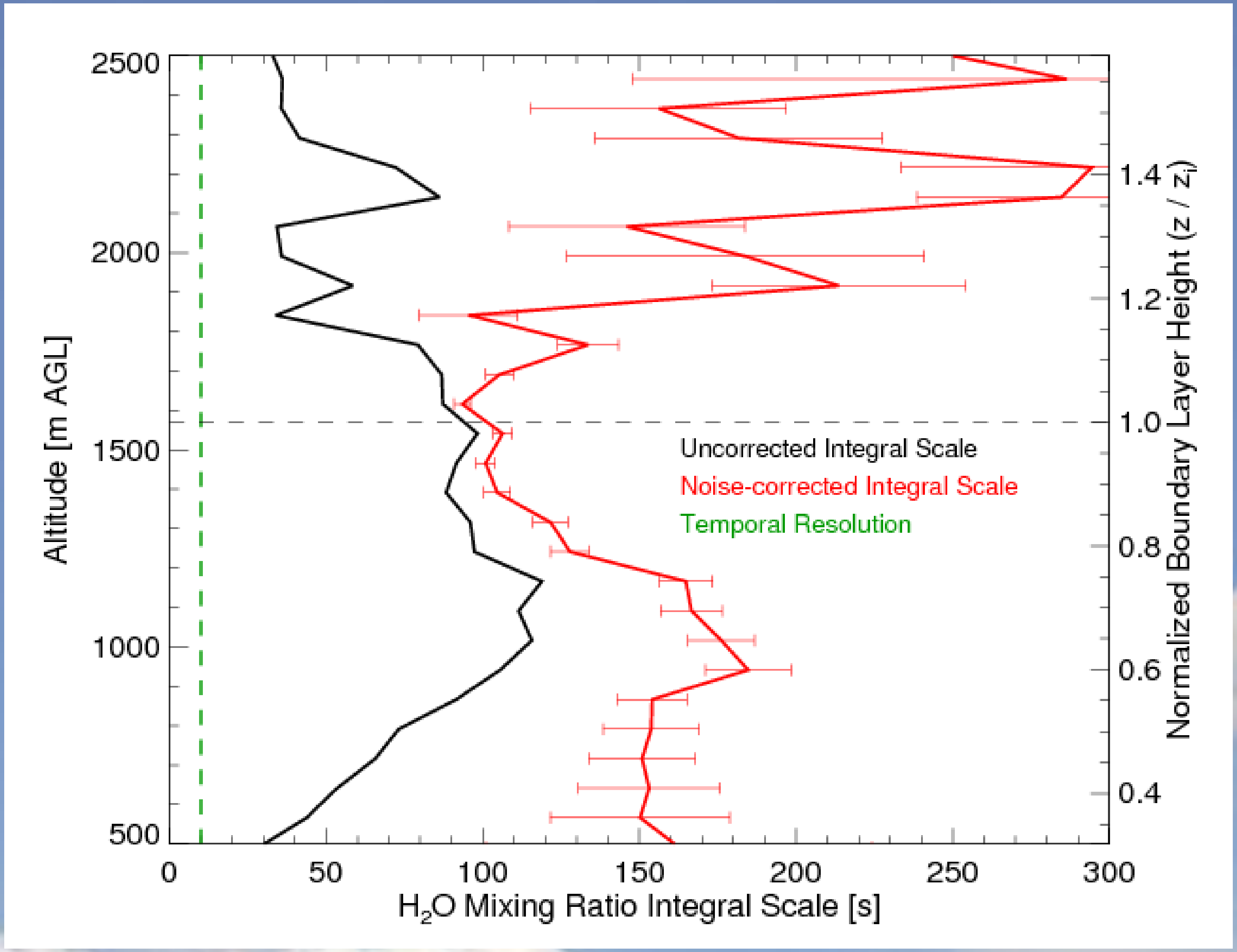
Instrument Noise Characteristics

22 Aug 2007 from 2200-2400 UTC



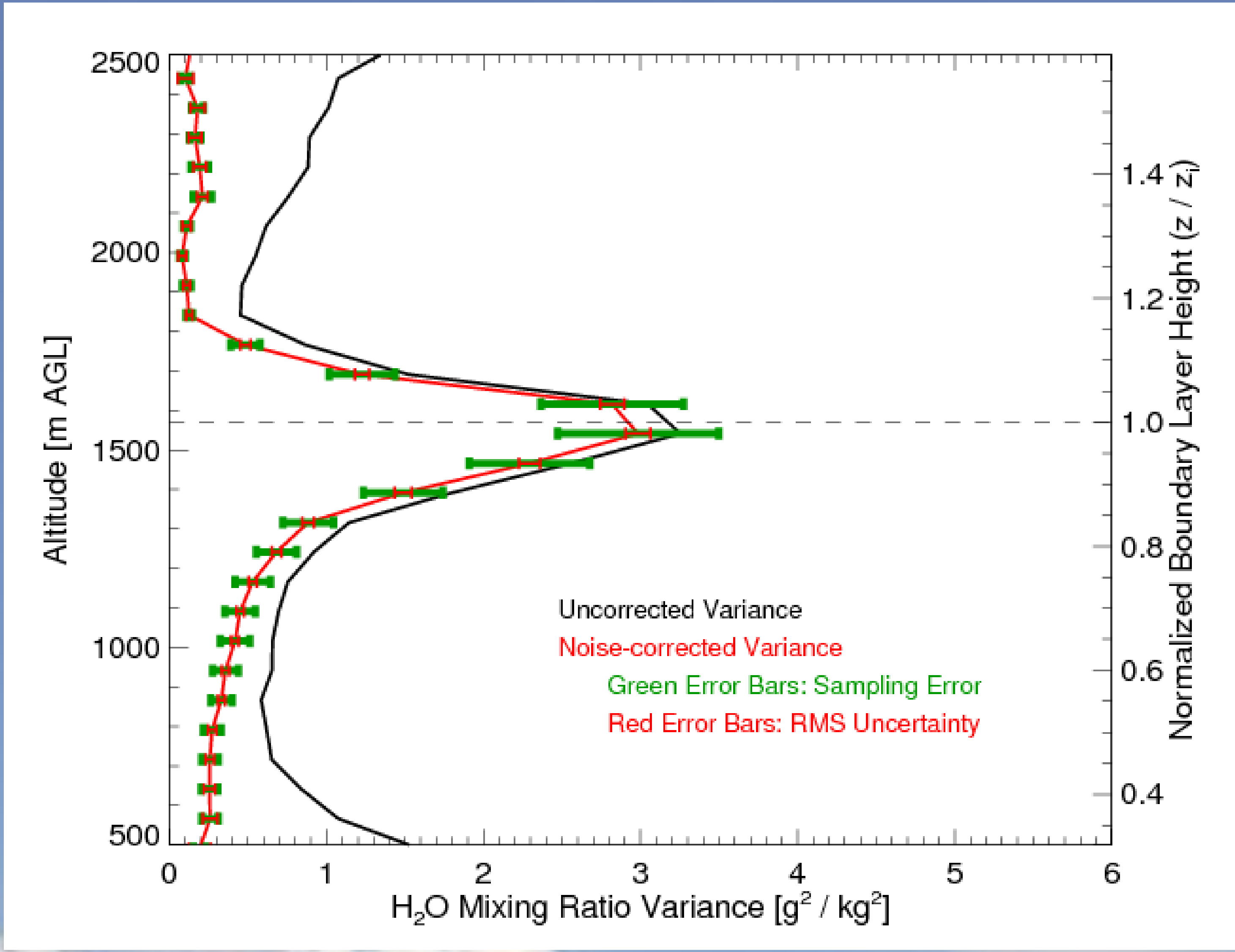
Integral Scale Profile

22 Aug 2007 from 2200-2400 UTC



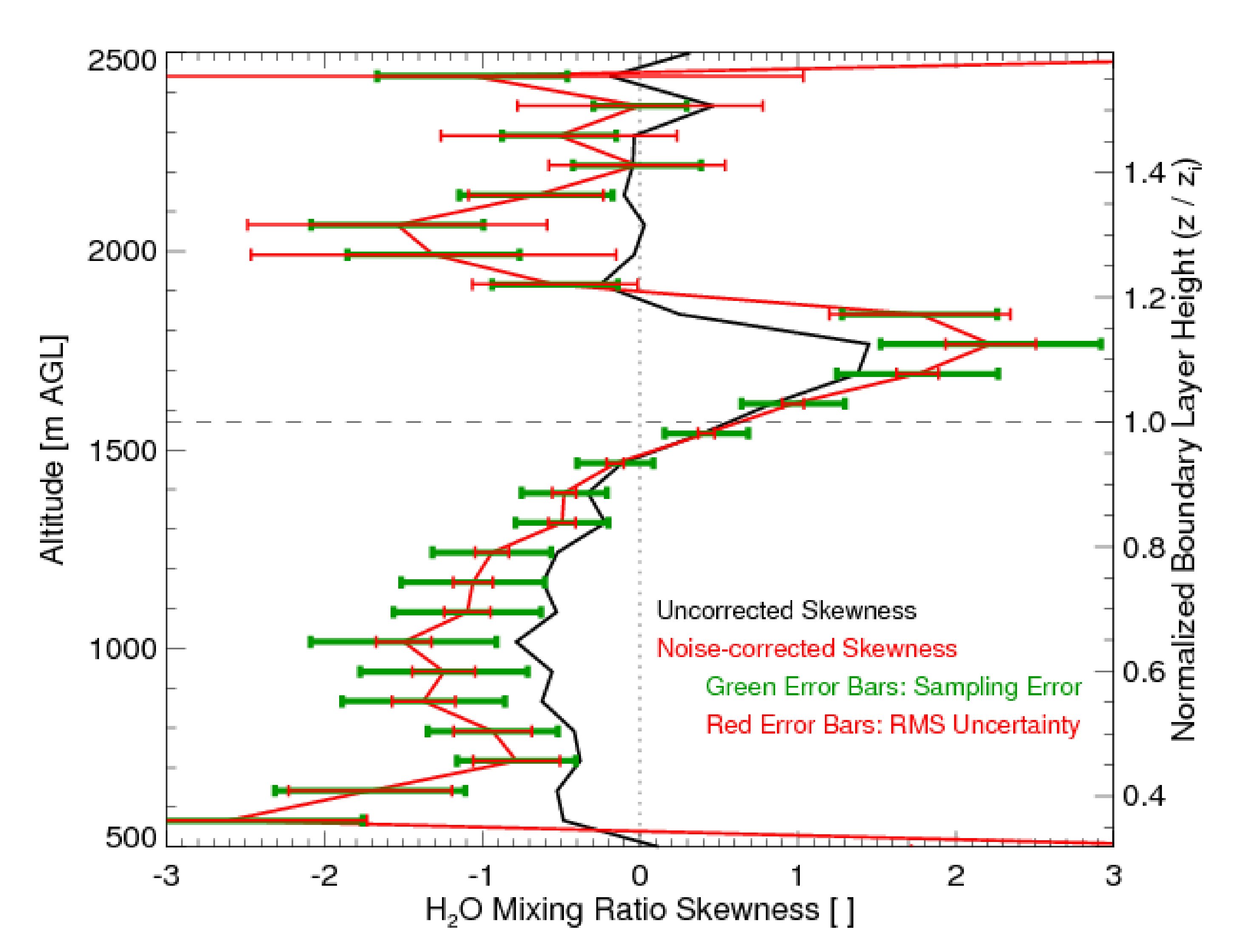
Atmospheric H_2O Variance Profile

22 Aug 2007 from 2200-2400 UTC



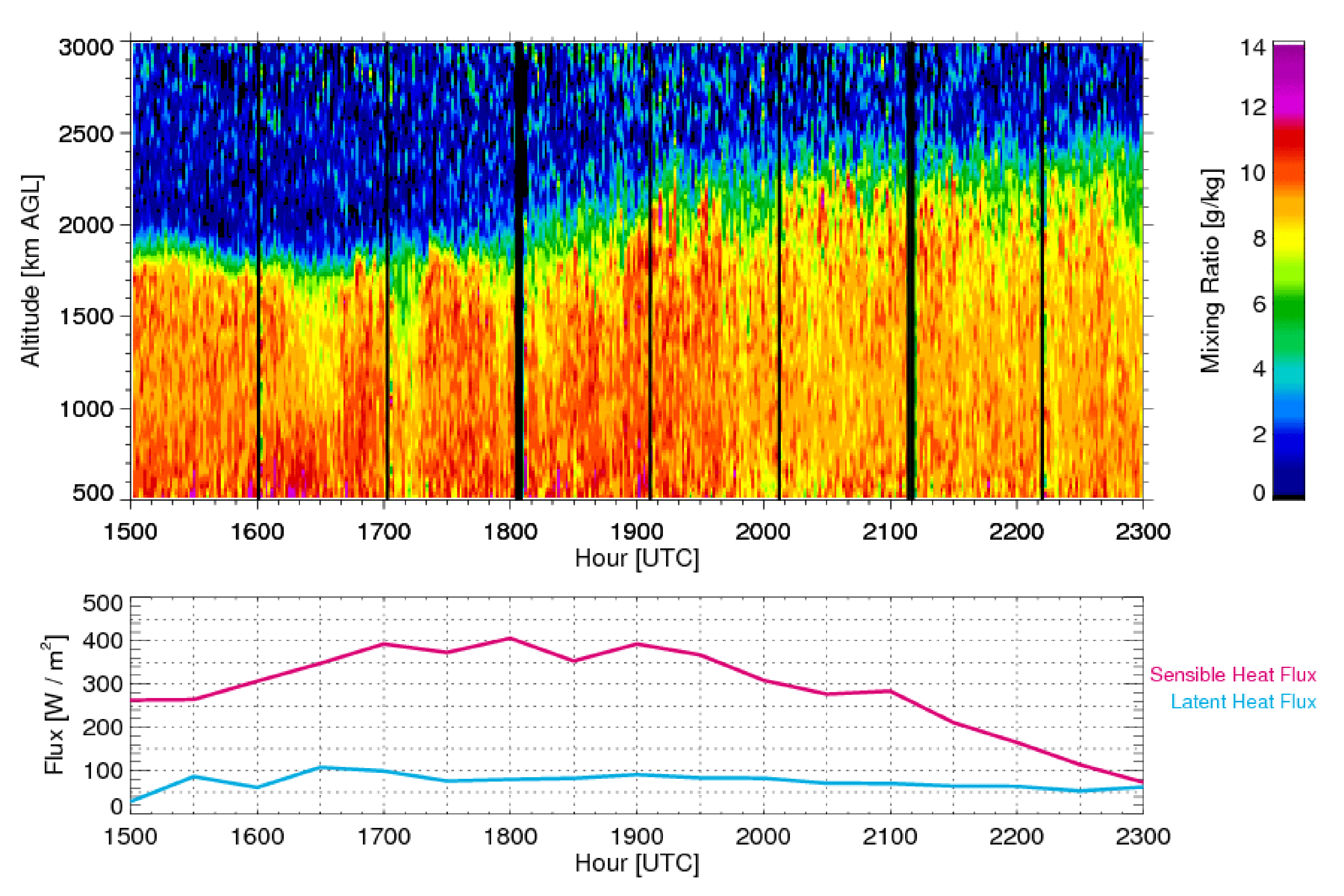
Atmospheric H_2O Skewness Profile

22 Aug 2007 from 2200-2400 UTC



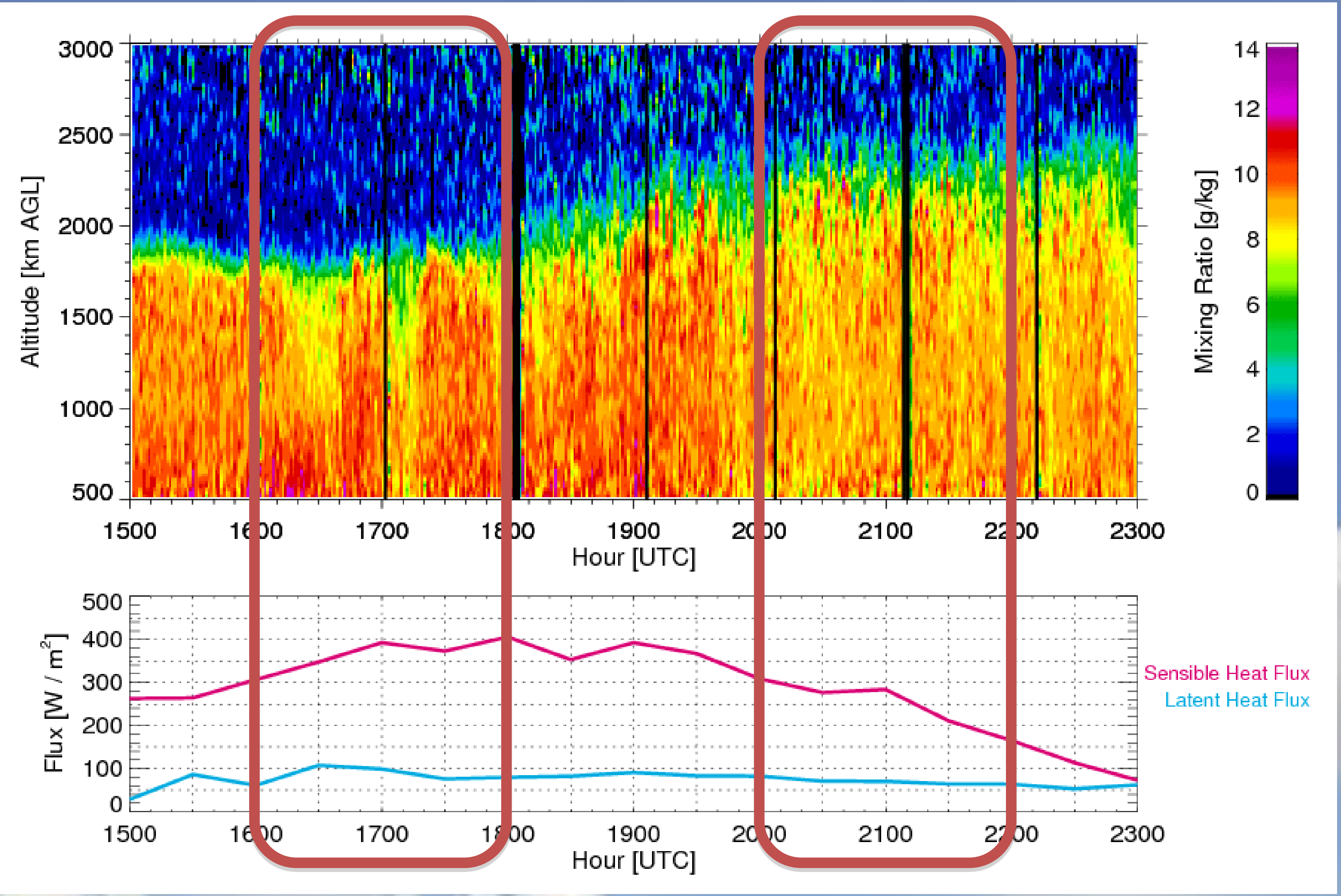
Evolution of the BL Turbulence

3 September 2007



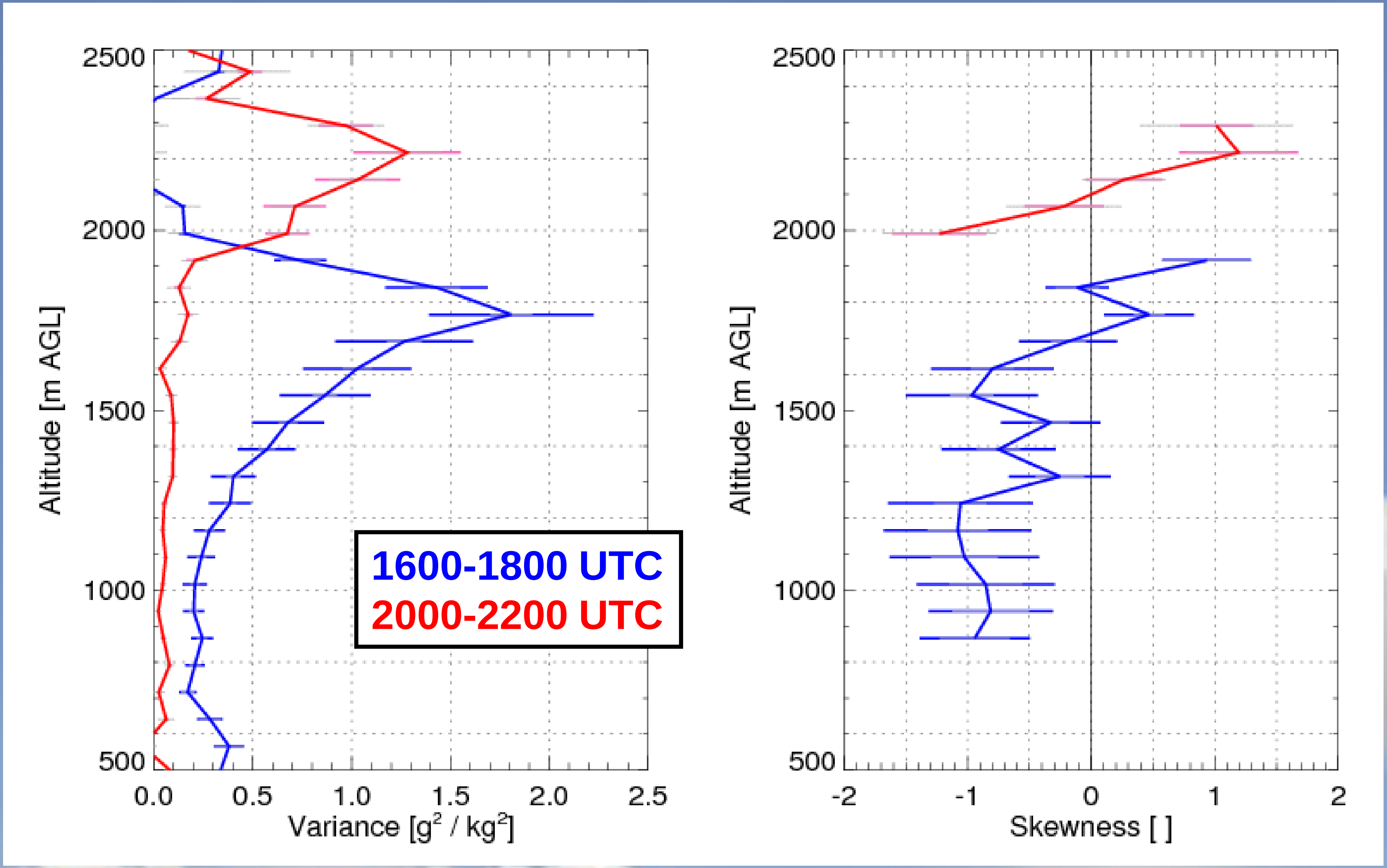
Evolution of the BL Turbulence

3 September 2007



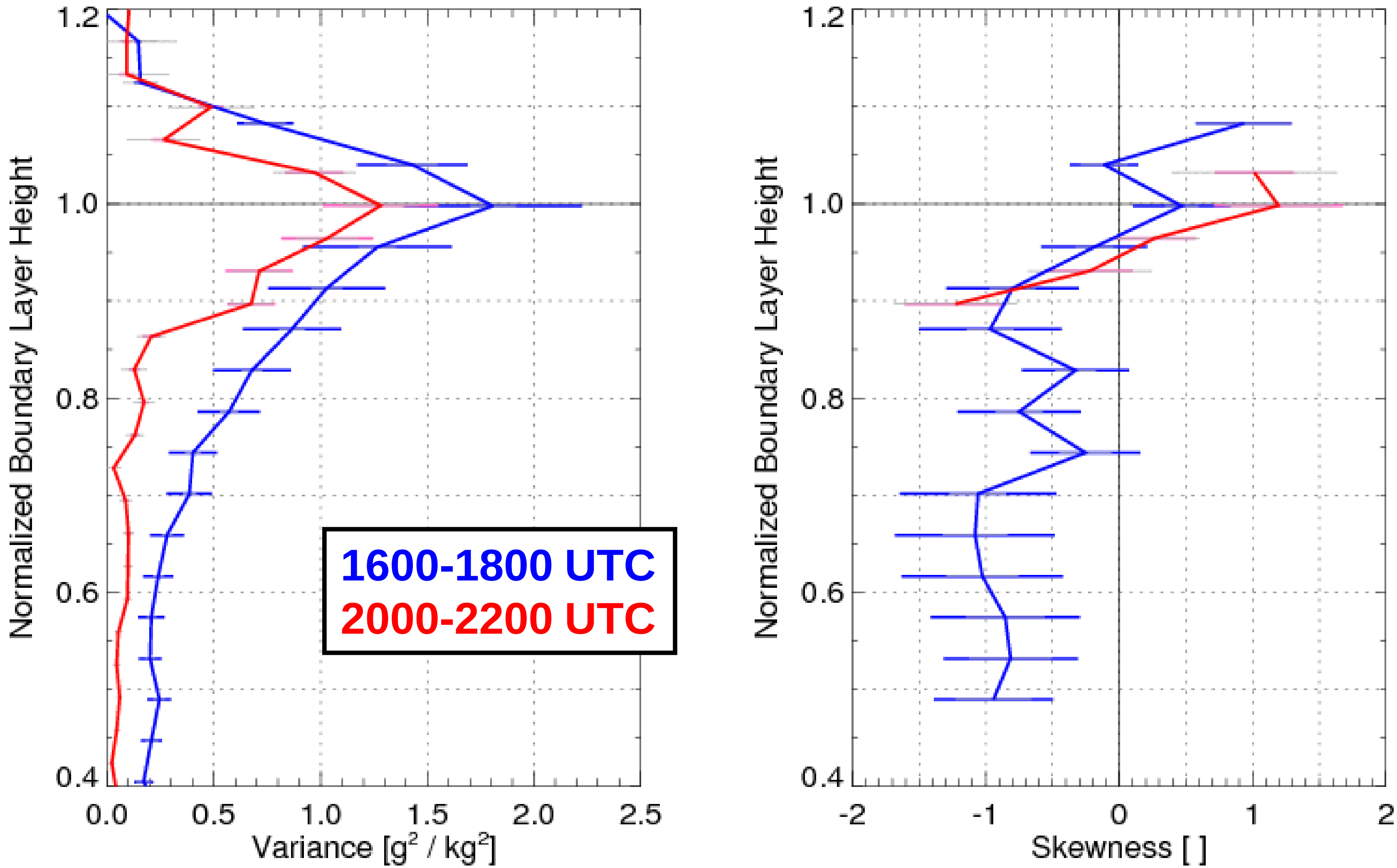
Variance and Skewness Profiles

3 September 2007: 1600-1800 and 2000-2200 UTC



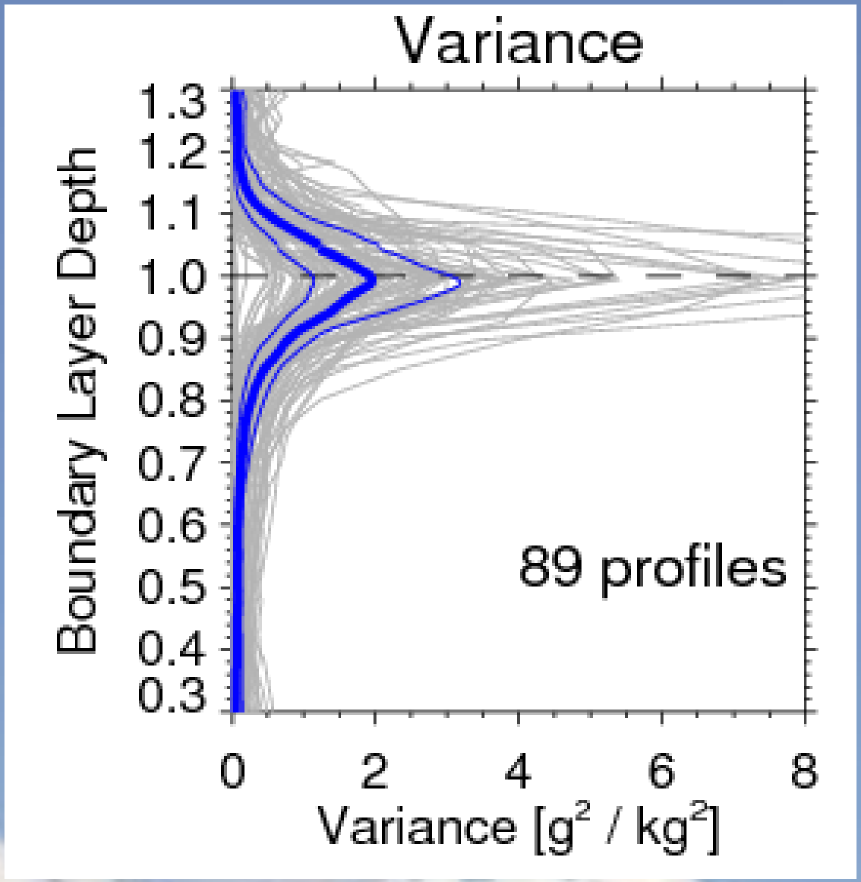
Variance and Skewness Profiles

3 September 2007: 1600-1800 and 2000-2200 UTC



How Does Variance and Skewness Vary?

- Cases will well-mixed daytime BLs from 2005 – 2009
- Only cases where $\sigma^2_{BLtop,instr} < 0.5 * \sigma^2_{BLtop,total}$



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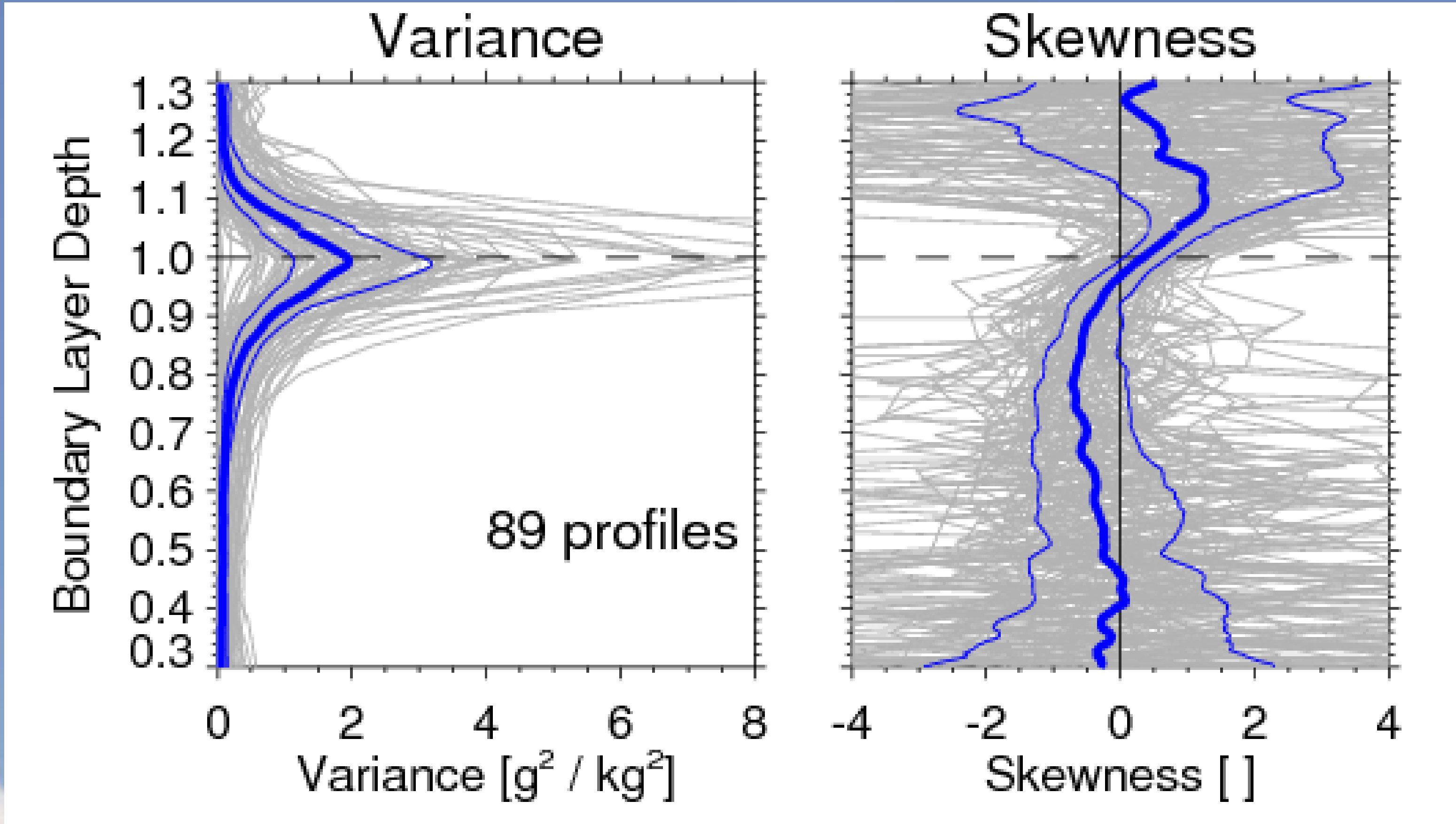
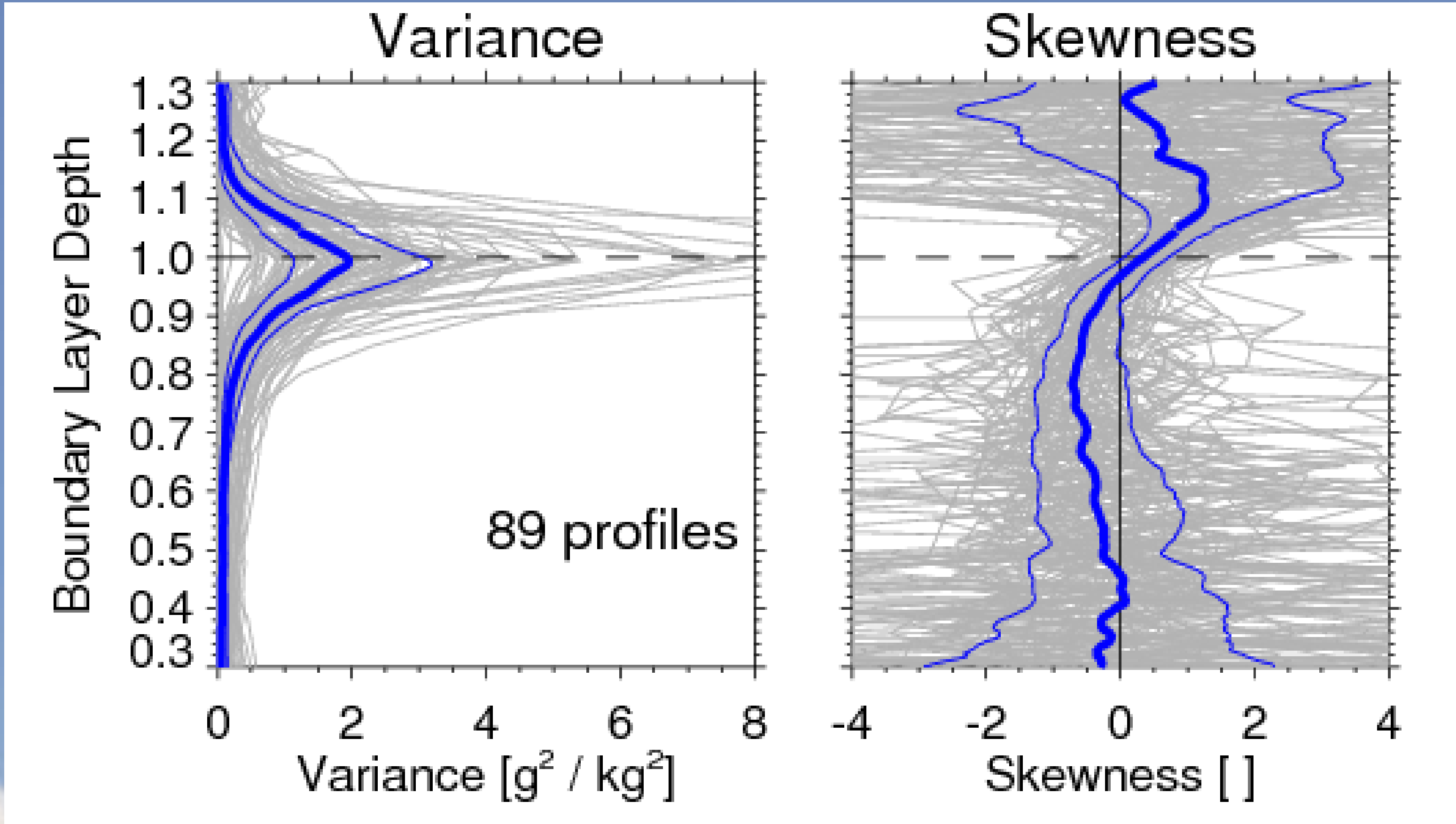


How Does Variance and Skewness Vary?

- Cases will well-mixed daytime BLs from 2005 – 2009
- Only cases where $\sigma^2_{BLtop,instr} < 0.5 * \sigma^2_{BLtop,total}$
- No significant correlations found with w_*, q_*, or h…

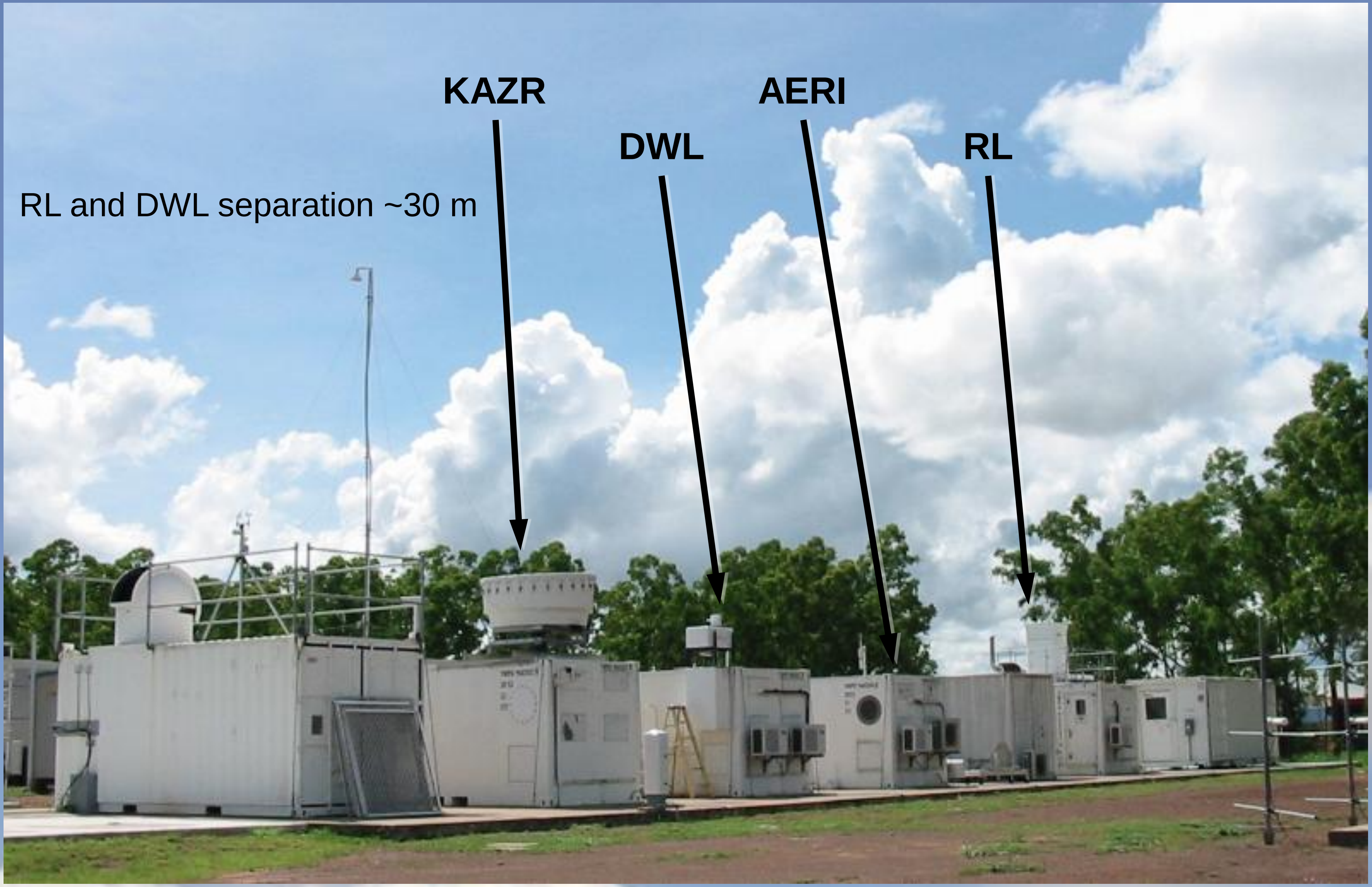


Doppler Wind Lidar

- Profiles of vertical velocity and w’
- Combined with RL water vapor to get water vapor fluxes
  - Need to consider horizontal separation (~300 m) of RL and DWL at SGP
- Only able to provide wind profiles in regions with aerosol (BL)
- How good will be the S/N at top of the BL?

Spatial Separation at TWP Darwin

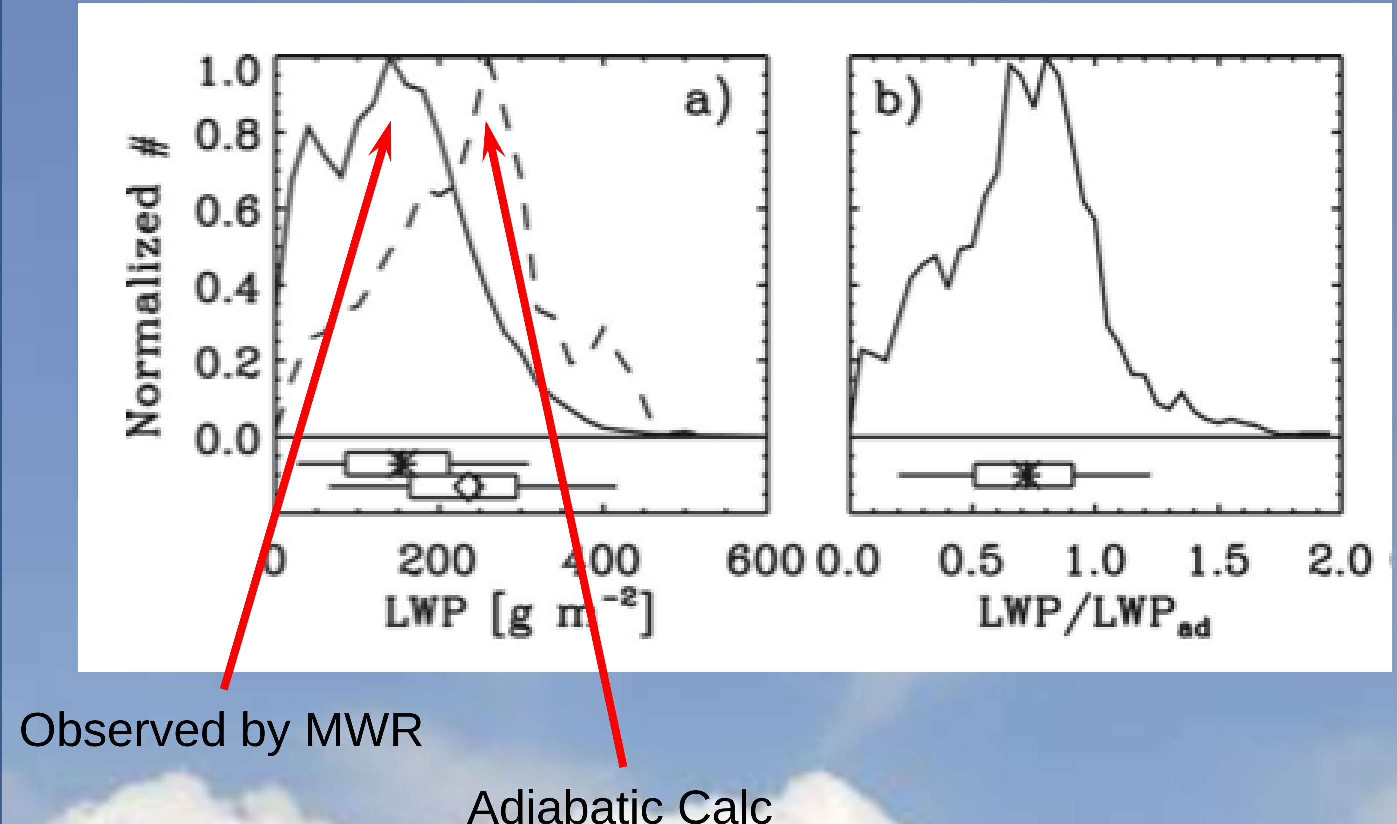
(not really an issue here)



Entrainment of Dry Air into Clouds

Sub-Adiabatic Fraction Useful?

- Easily compute the adiabatic LWP of a cloud
- Ratio of measured LWP to LWP_{ad} could be a proxy for entrainment rate



Distribution of LWP ratio during M-PACE

Surface forcing quite strong due to open ocean

Shupe et al. JAS 2008

Sub-Adiabatic Fraction Useful?

- Easily compute the adiabatic LWP of a cloud
- Ratio of measured LWP to LWP_{ad} could be a proxy for entrainment rate
- How often do (near) adiabatic conditions hold?
- How accurate is the assumed adiabatic LWP, given cloud boundary uncertainties (esp determining cloud top)?
- How do uncertainties in observed LWP impact this ratio?

- Clearly, this ratio becomes more accurate as the cloud thickness and LWP increase
  - LWP_{ad} less sensitive to cld boundary uncertainty as cld becomes thicker
  - Most clouds are "thin" with LWP < 100 g/m^2
  - Geometrically thicker (deeper) clouds probably are less adiabatic than their thinner cousins

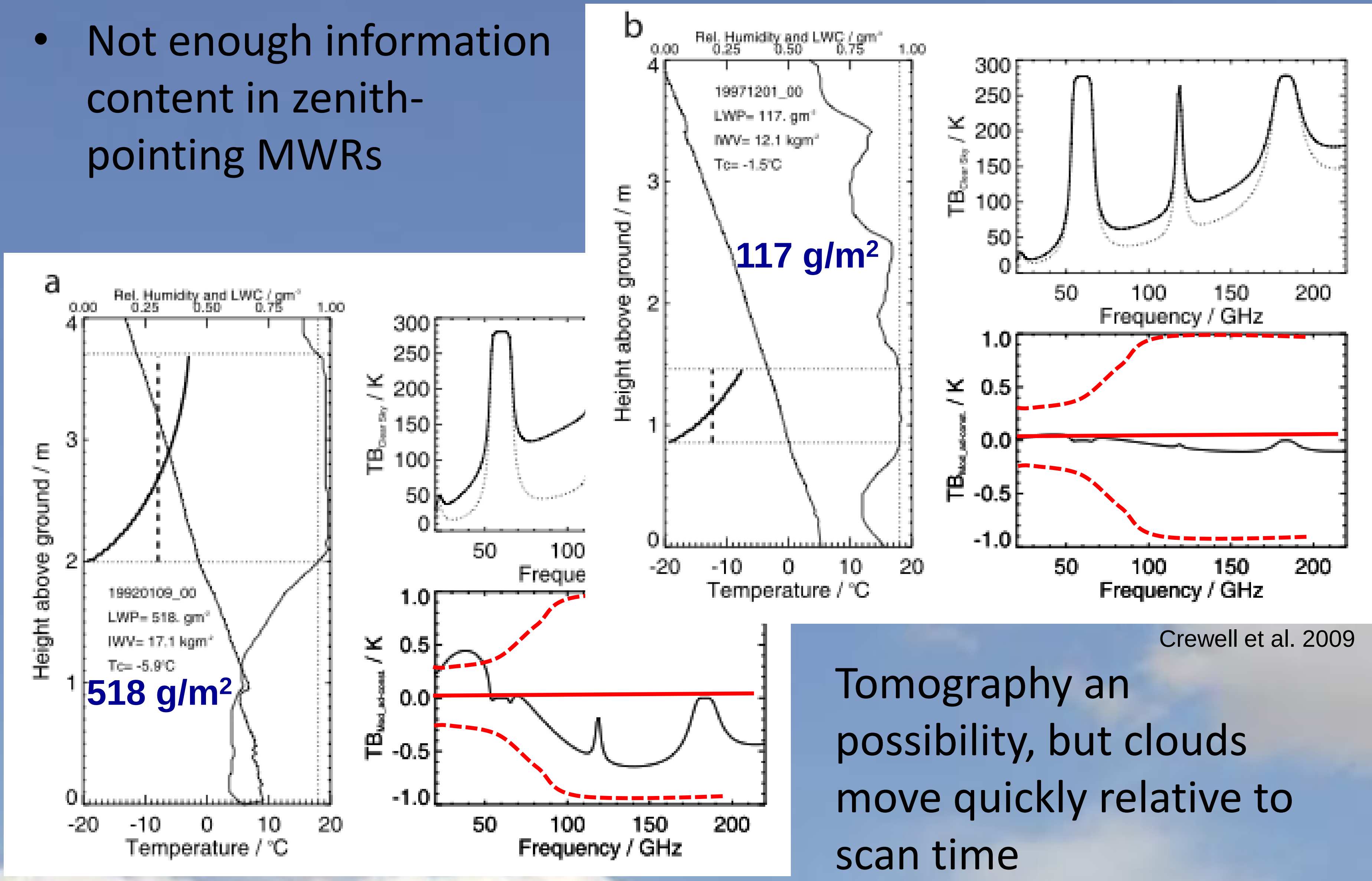
Entrainment of Dry Air into Clouds

Key Geophysical Parameters Needed

- Profiles of thermodynamics outside cloud (including above cloud)
- Profiles of LWC
- Profiles of Reff or DSD

LWC Profiles from Passive Sensors?

- Not enough information content in zenith-pointing MWRs



Crewell et al. 2009

Tomography an possibility, but clouds move quickly relative to scan time

Combining Single Freq Cloud Radar and MWR

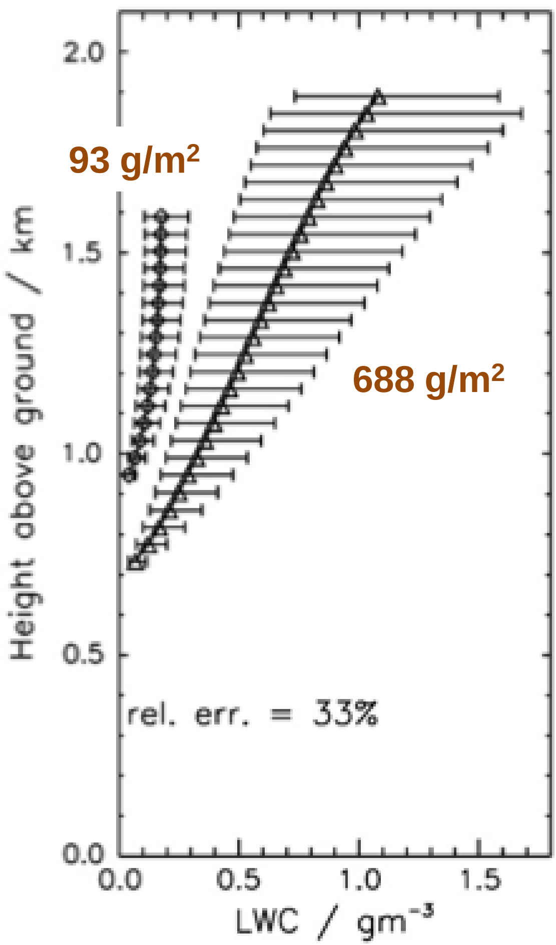


Fig. 2. Example for the retrieved errors of the LWC profiles in Fig. 1. A TB error of 0.5 K and an a priori uncertainty of $\log(\mathrm{LWC/gm^{-3}}) = 0.175$ (corresponding to a relative a priori uncertainty of 34%) is assumed. In this example, the retrieval includes the MWR brightness temperatures of the K-band only.

- Ka band cloud radar
- MWR with various chs
  - K-band (22-31 GHz)
  - V-band (50-60 GHz)
  - 90 and 150 GHz
- For reasonable uncertainties in prior and observations, still get ~33% uncertainty in retrieved LWC

Ebell et al. 2010

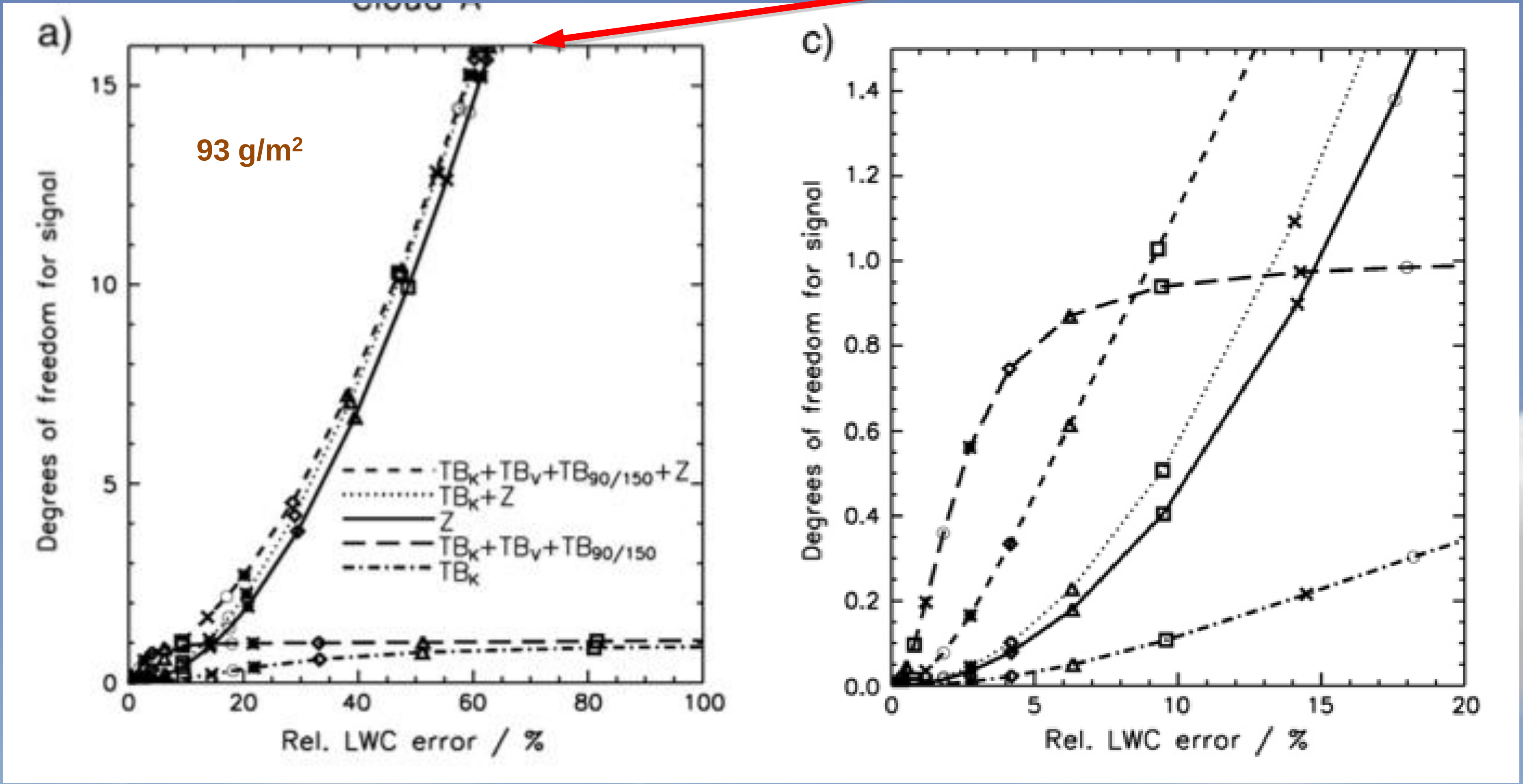
Synergy of Sensors in LWC Retrieval

Dependence of DFS on LWC Error

Uncertainty in Z: 3 dB

Uncertainty in Tb: 0.5 K

Maximum DFS: 16

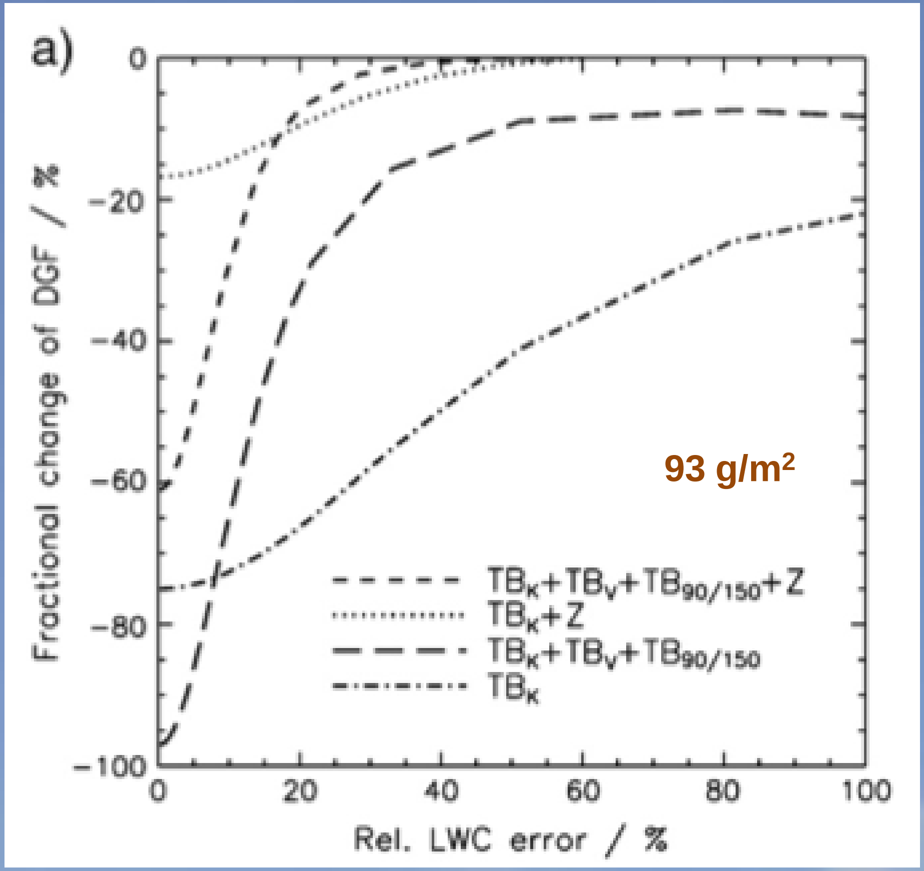


Ebell et al. 2010

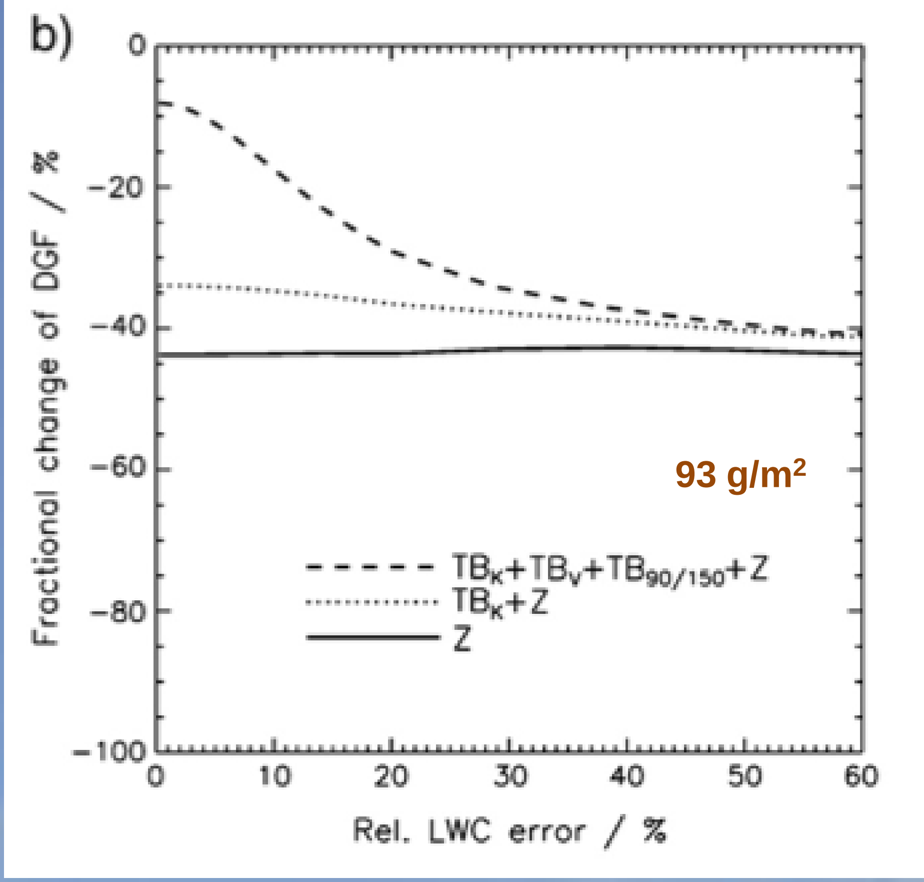
Increasing the Observational Uncertainty

Impact on DFS in LWC Retrieval

Tb Uncertainty from 0.5 to 1.0 K



Z Uncertainty from 3 to 4 dB

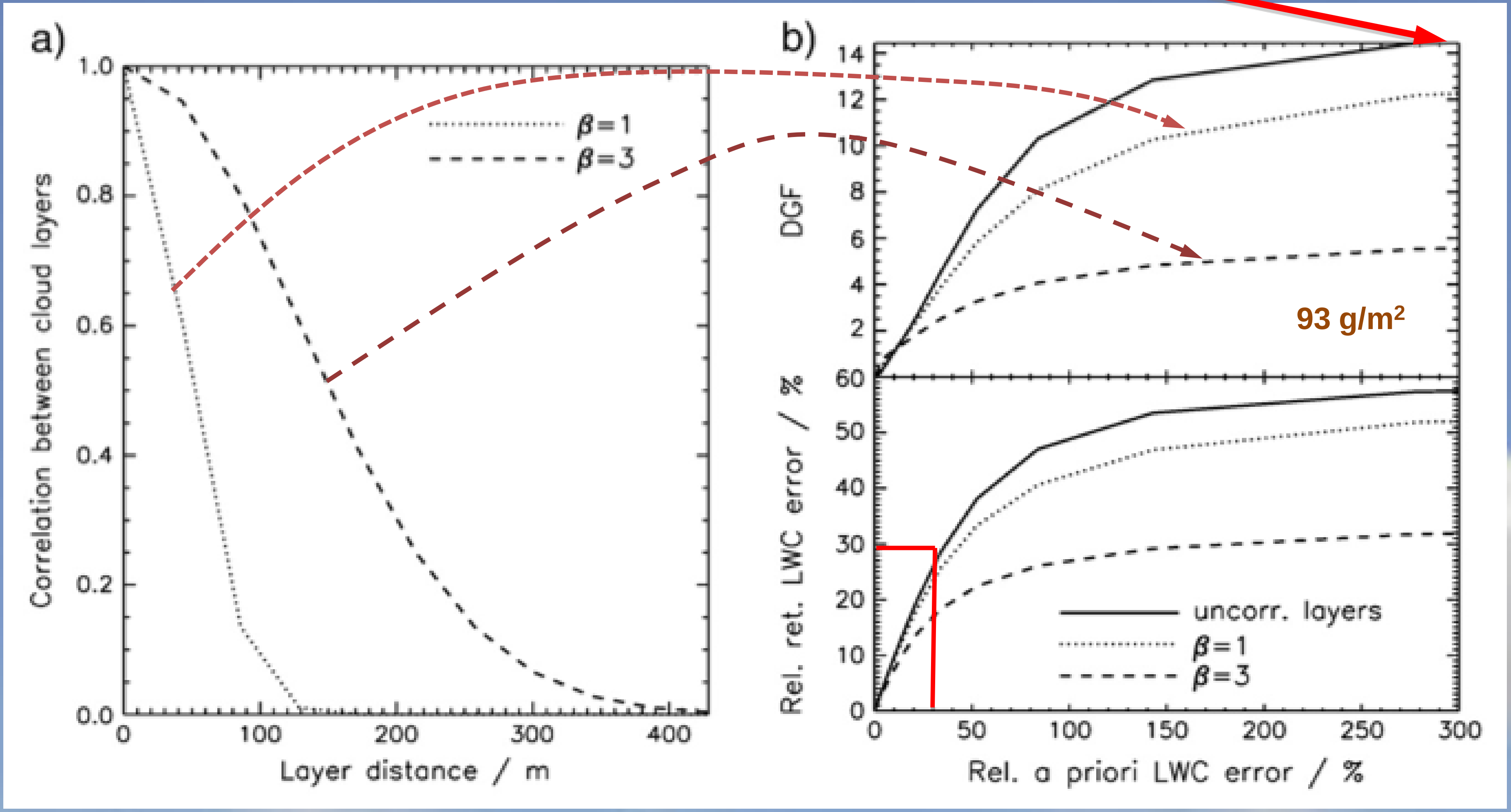


Ebell et al. 2010

Adding Vertical Correlation to Prior

Connection btwn Prior Uncertainty and DFS and Posterior

Maximum DFS: 16



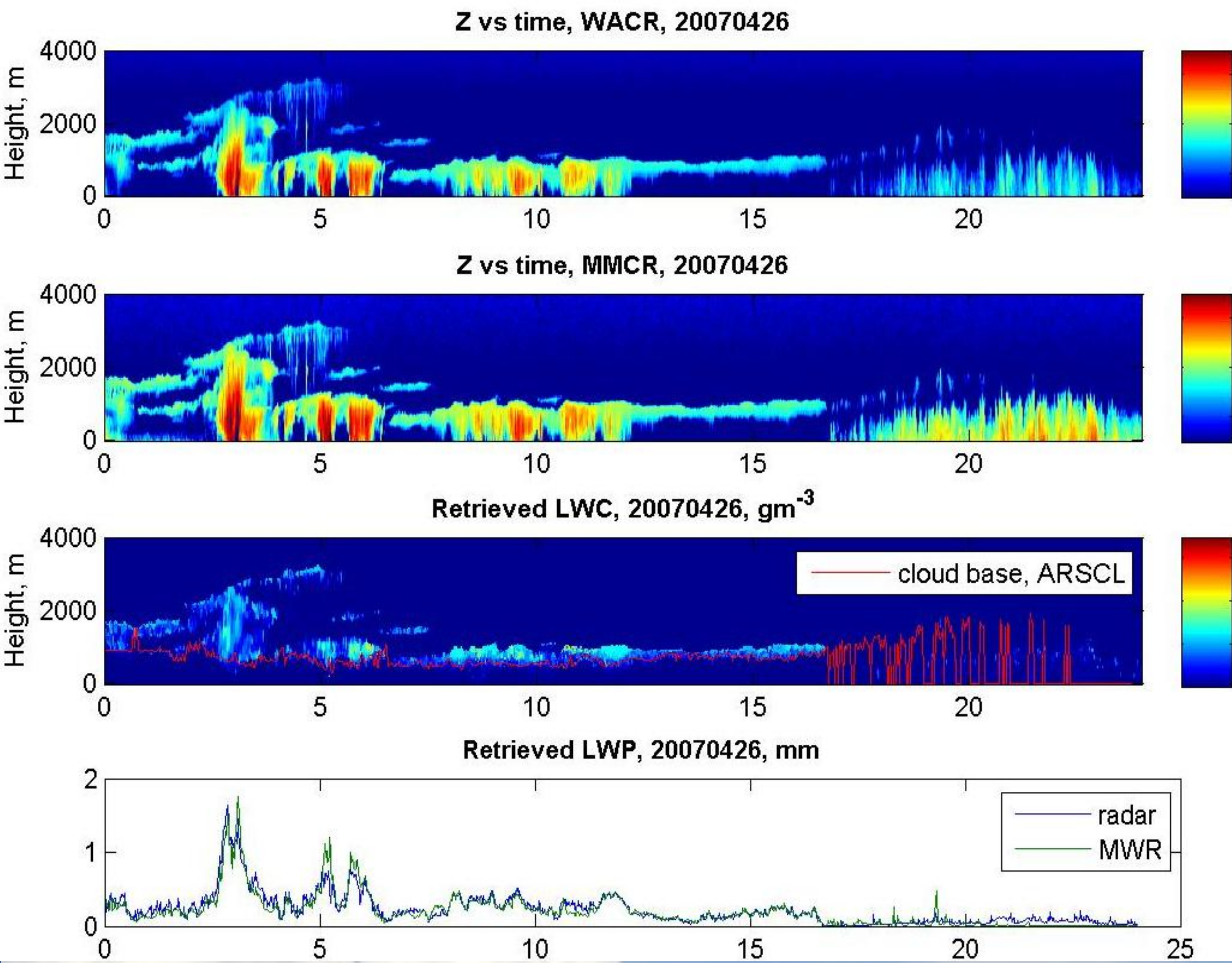
Ebell et al. 2010

What About Dual-Freq Approaches?

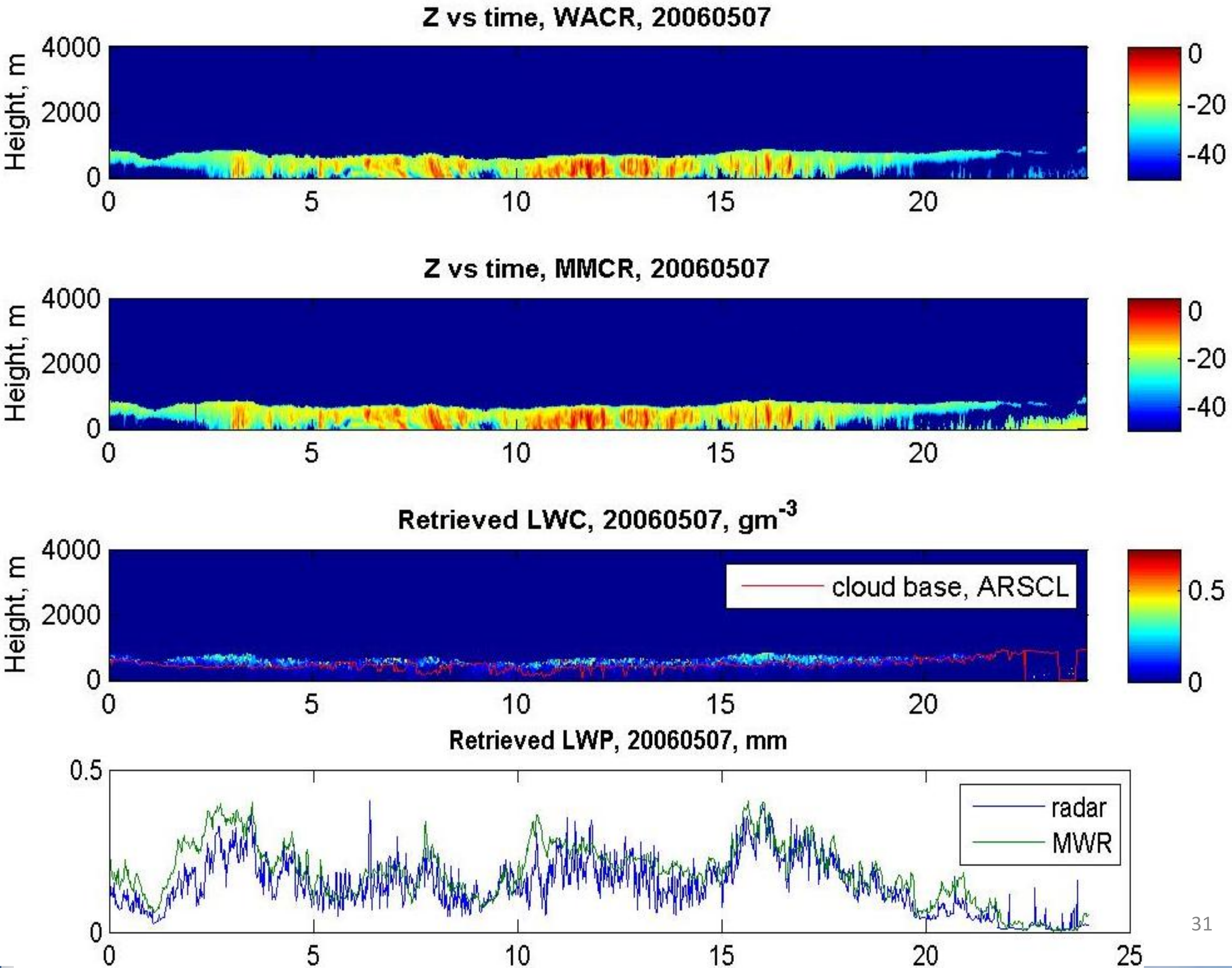
(E.g., Differential Absorption at W and Ka)

LWC from Differential Absorption

- Using Ka- and W-band, each 1 dB difference is ~120 g/m^2
- Assumes in Rayleigh scattering regime
- Absolute calibration accuracy not required
  - Relate relative calibration from each radar at cloud base
- Precise (low-noise) observations of reflectivity required
- Inversion problem is well-posed, but direct derivation challenging due to noise in data
- Need to formulate as a retrieval problem
  - Brings in additional information to help constrain solution
  - Some success with topographic techniques
  - Need to quantify the info content of obs vs. prior from retrieval
  - What is the accuracy? The error covariance between levels?
- Dong Huang's method agrees with MWR LWP w/i 30-80 g/m^2



Huang, Fall ARM WG, 2008



Huang, Fall ARM WG, 2008

Where does this leave us?

- BL / free tropospheric exchange
  - Have a method to determine WV turbulent profiles in convective BLs
  - If can overcome the horizontal spacing issue, likely can determine WV fluxes at SGP (almost certainly can at Darwin)
    - Still need to characterize how well the DWLs work for w' statistics
  - RL analysis is limited to SGP and TWP-Darwin sites
  - Research needs to be done to see if similar results can be derived from AERI retrievals at other sites
- Cloud entrainment
  - Methods appear more promising for thicker clouds with larger LWP
  - Unfortunately, more than 50% of clds have LWP < 100 g/m^2
  - Probably should concentrate initially on warm, non-precipitating clds
    - Mixed-phase will generate large uncertainties in radar analysis
    - Precipitation hinders adiabatic, and perhaps Rayleigh, assumptions
  - Would there be benefit to looking at profiles of Reff instead of LWC?

An Approach?


Wall of Wisdom
"ENLIGHTENMENT THROUGH BEER"
WISDOMS
WORLD LEGENDS

Extra Slides

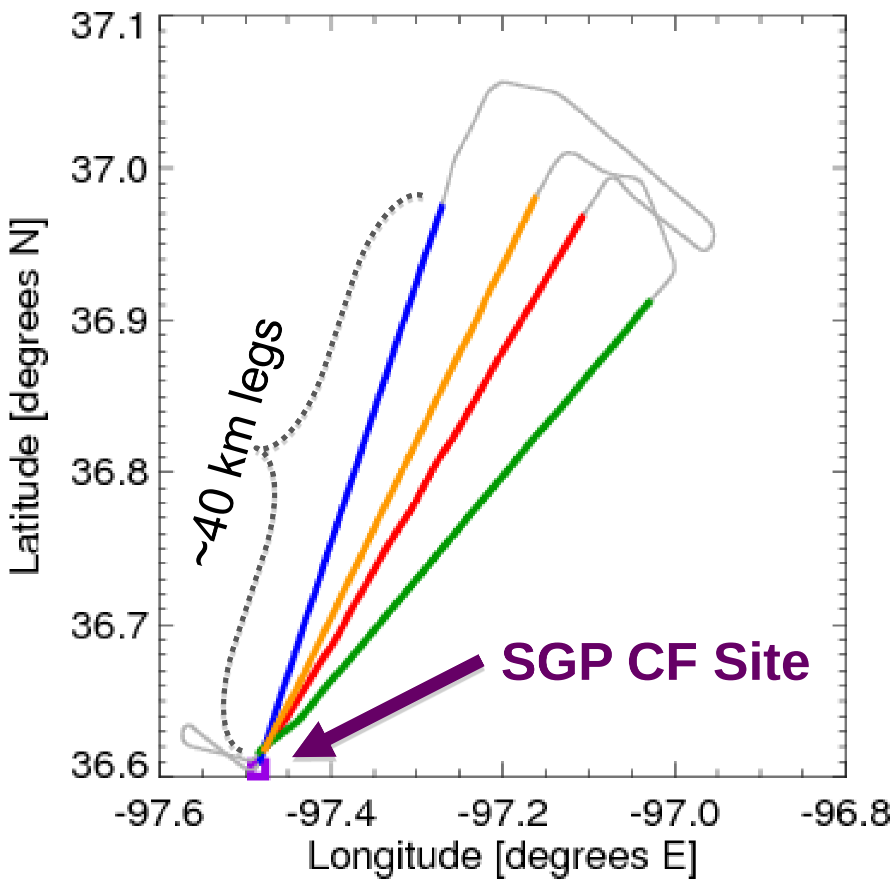
Comparison With Aircraft Observations

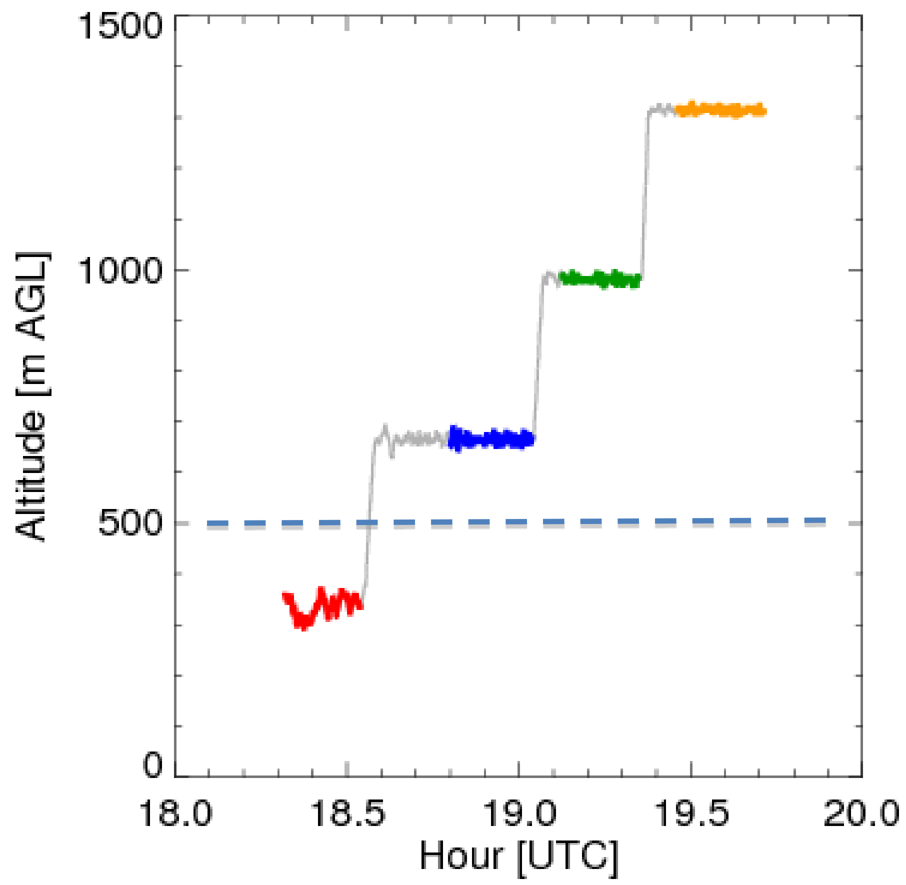
The CIRPAS Twin Otter

Twin Otter carried a diode laser hygrometer operating at 90 Hz during RACORO Field Campaign (Jan-Jun 2009)

Twin Otter Flight Path

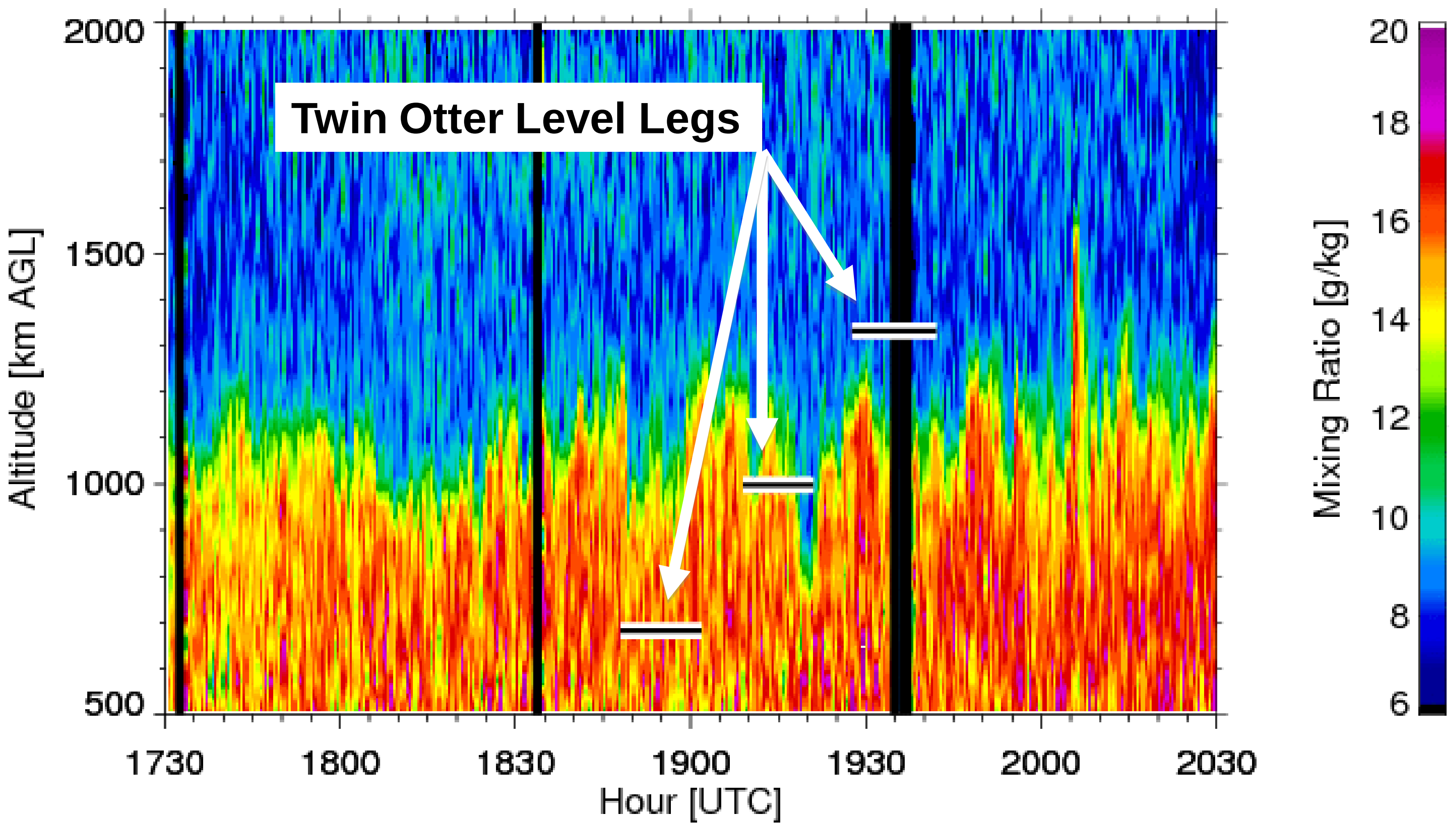
15 June 2009





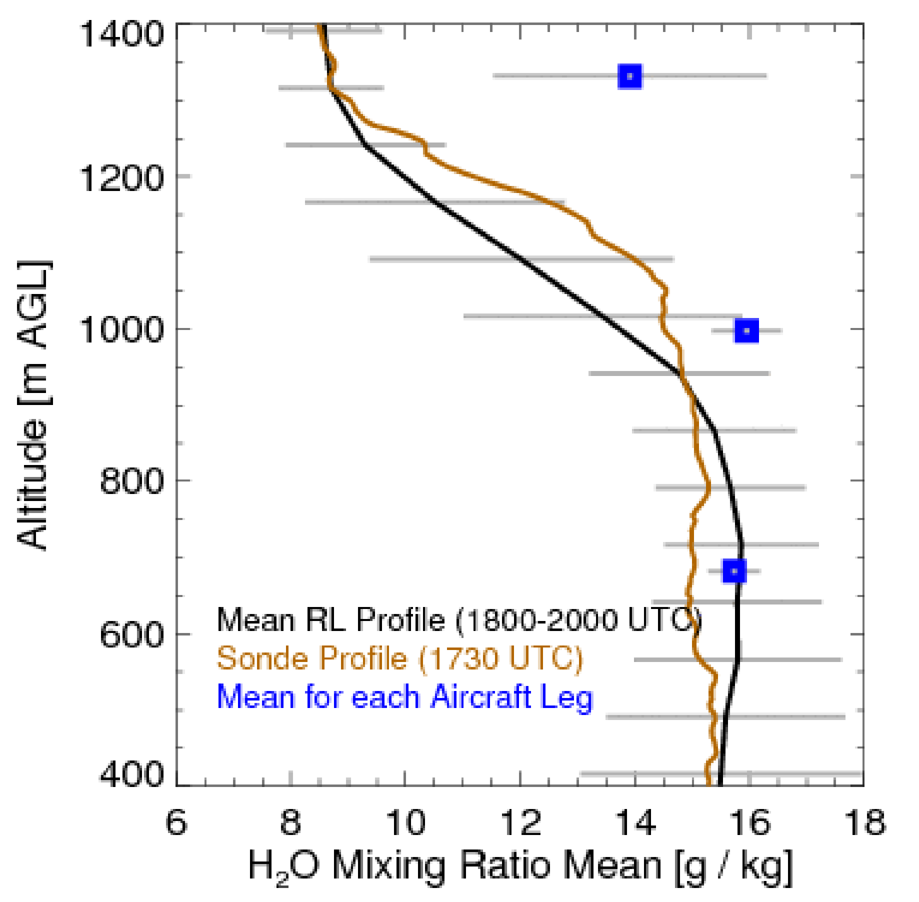
Time-Height Cross-Section of H_2O by RL

15 June 2009



Mean and Variance H_2O Profiles: Initial

15 June 2009



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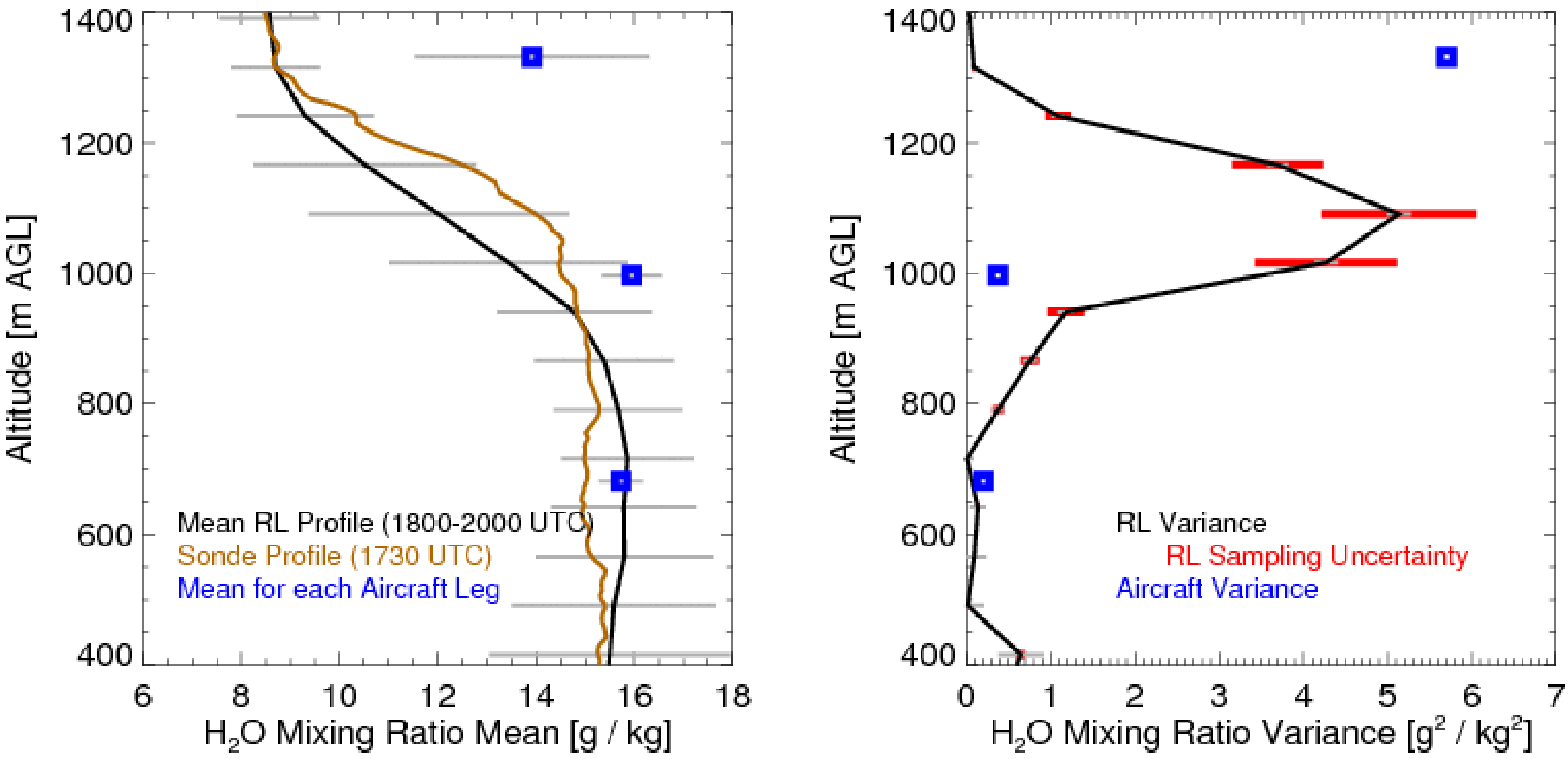
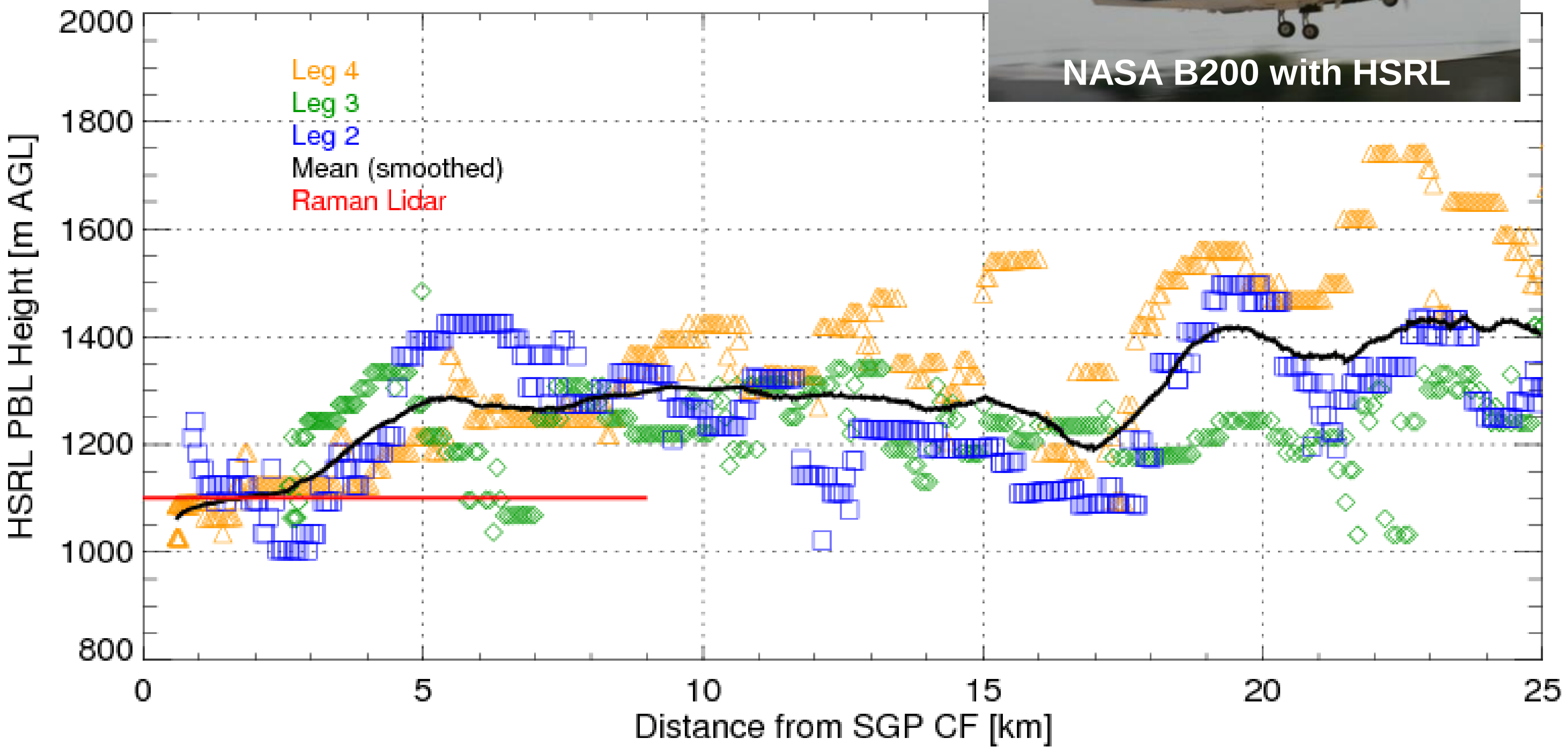


Boundary Layer Height Away from SGP CF

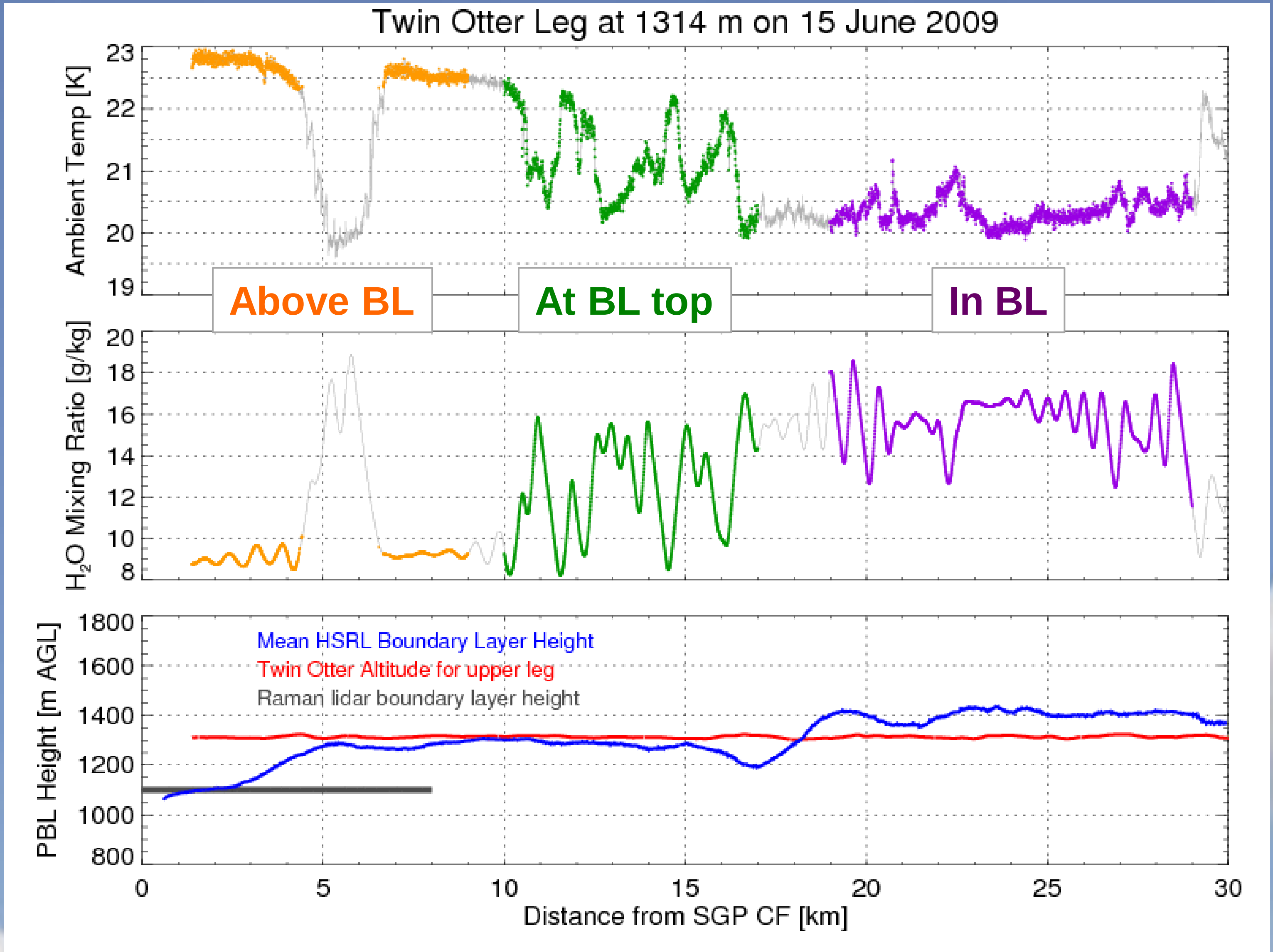
15 June 2009



HSRL Data Courtesy of Dr. Rich Ferrare

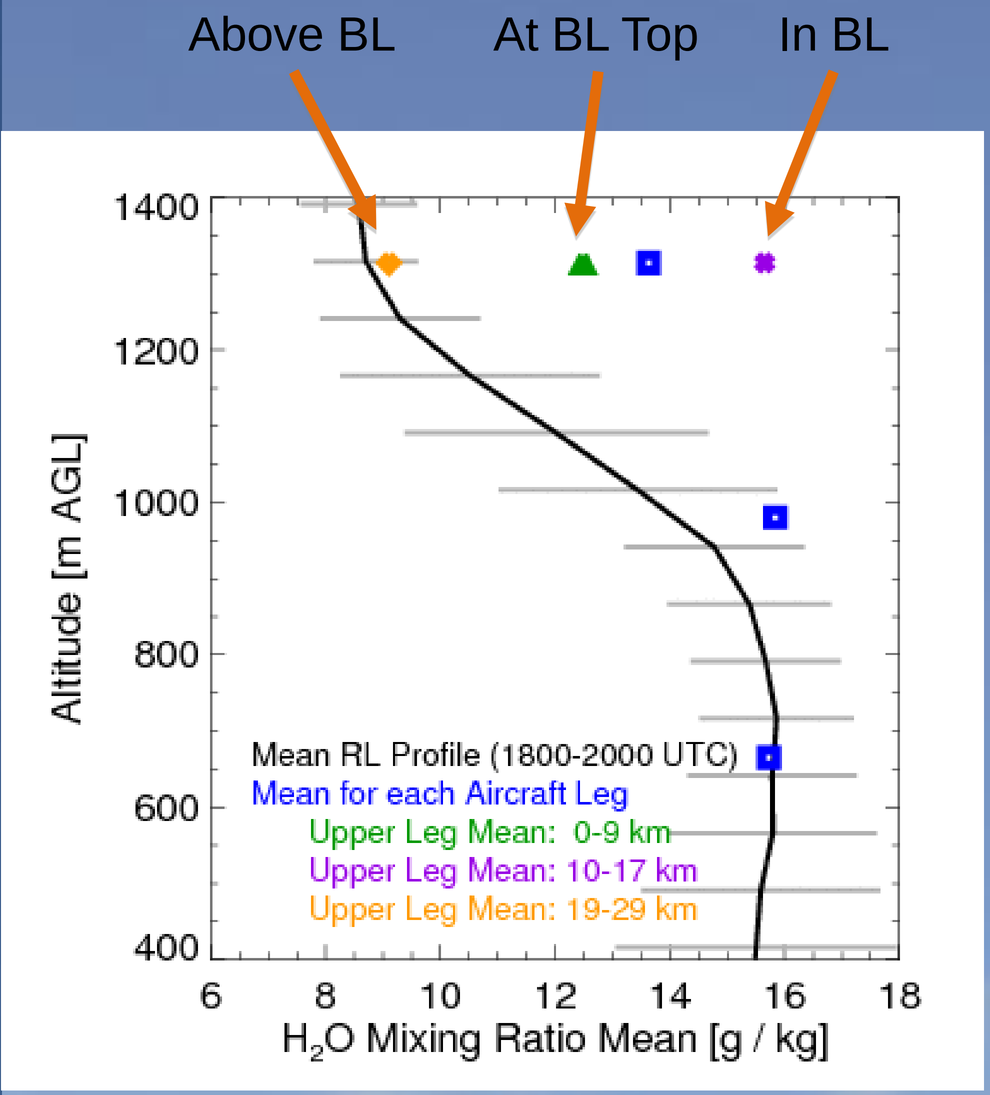
Analysis of Upper Twin Otter Flight Leg

15 June 2009



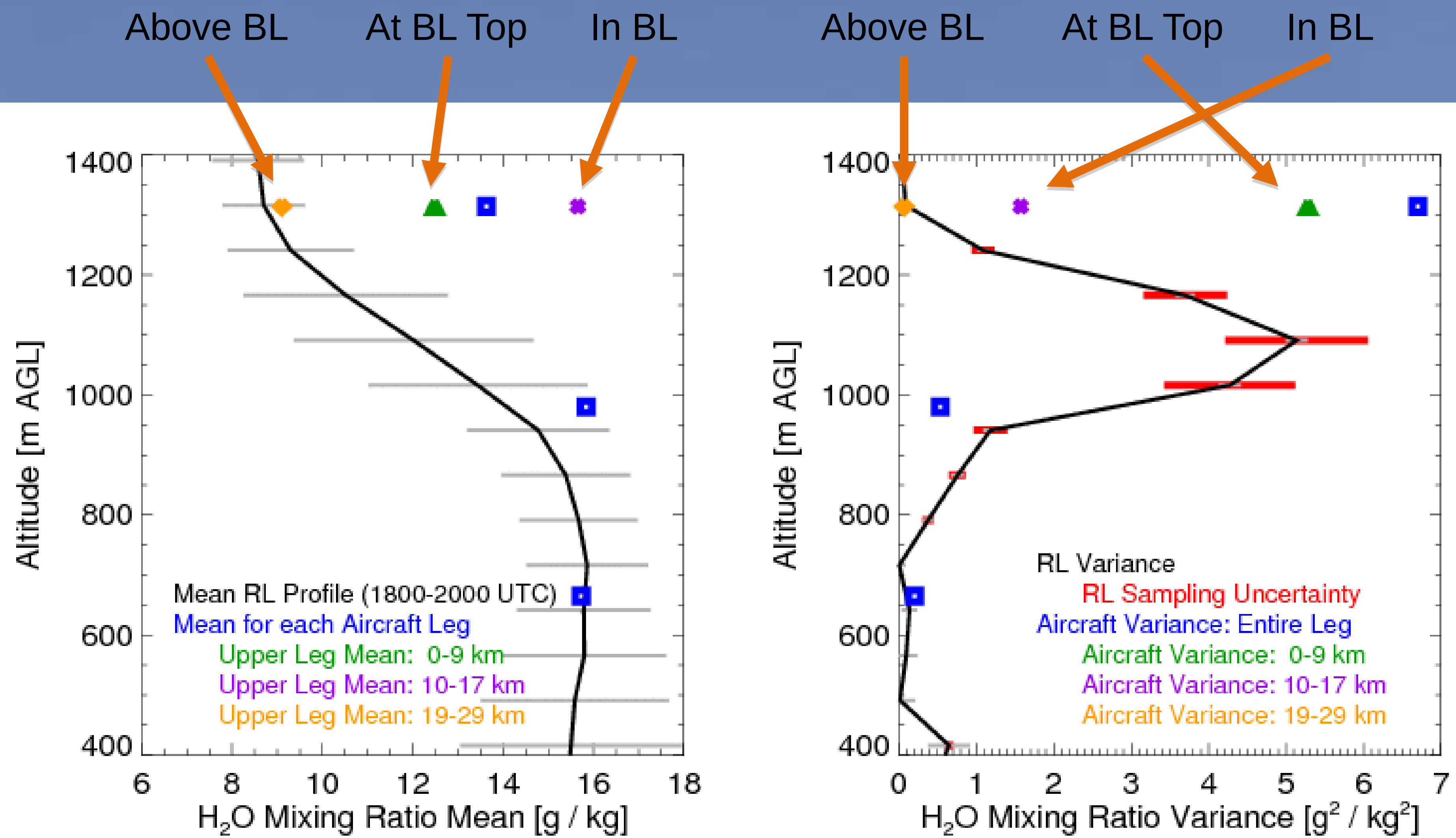
Mean and Variance H_2O Profiles: Refined

15 June 2009



Mean and Variance H_2O Profiles: Refined

15 June 2009



Mean and Variance Normalized Profiles

15 June 2009